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Application No.	S2002/0934
Date of Filing	3 December 2002
Applicant	MONTAGUE KENYON LIMITED an Irish company, of Annaville House, Newtown, Waterford, Ireland.

Dated this 10 day of December 2003.

An officer authorised by the
Controller of Patents, Designs and Trademarks.

FORM NO. 1

S020934

Request for the Grant of a Patent No.

PATENTS ACT, 1992

The Applicant(s) named herein hereby request(s)

☐ the grant of a patent under Part II of the Act

☒ the grant of a short-term patent under Part III of the Act

on the basis of the information furnished hereunder

1. **Applicant(s)**

Name MONTAGUE KENYON LIMITED

Address Annaville House
Newtown
Waterford
Ireland

Description/Nationality an Irish company

2. **Title of Invention** GOLF DRIVE MEASUREMENT AND PRACTCE DEVICE

3. **Declaration of Priority on basis of previously filed application(s) for same invention (Sections 25 & 26)**

Previous Filing Date	Country in or for which Filed	Filing No.
....	....	....
....	....	....
....	....	....

4. **Identification of Inventor(s)**

Name(s) of person(s) believed by Applicant(s) to be the Inventor(s)

....

Address ....

....

5. **Statement of right to be granted a patent (Section 17(2)(b))**

....

....

6. **Items accompanying this Request - tick as appropriate**

(i) ☒ prescribed filing fee (€60.00)

(ii) ☐ specification containing a description and claims

☒ specification containing a description only

☐ drawings referred to in description or claims

(iii) ☐ an abstract

(iv) ☐ copy of previous application(s) whose priority is claimed

(v) ☐ translation of previous application whose priority is claimed

(vi) ☐ Authorisation of Agent (this may be given at 8 if this Request is signed by the Applicant(s)

7. **Divisional Application(s)**

The following information is applicable to the present application which is made under Section 24:-

Earlier Application No. .... Filing Date ....

8. **Agent**

The following is authorised to act as agent in all proceedings in connection with the obtaining of a patent to which this request relates and in relation to any patent granted:-

MACLACHLAN & DONALDSON, 47 Merrion Square, Dublin 2

9. **Address for Service (if different to that at 8)**

MACLACHLAN & DONALDSON, at their address as recorded for the time being in the Register of Patent Agents (Rule 92)

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0 3 DEC 2002

Signed Name(s) MONTAGUE KENYON LIMITED

By ....

MACLACHLAN & DONALDSON, Applicants' Agents

Date 3rd December 2002

GOLF DRIVE MEASUREMENT AND PRACTICE DEVICE

The present invention relates to a method and apparatus for measuring the flight characteristics of a ball which has been struck by a moving object. The invention relates more specifically, but not exclusively, to a method and apparatus for measuring the flight characteristics of a golf ball, which has been struck by a golf club in a drive shot.

The game of golf is one of the most popular universal sports. As is well known, it comprises sets of shots, each set typically involving an initial long drive shot from a starting tee, followed by a series of progressively shorter shots towards a hole on a green. Most golf players, from beginners to professionals, reserve their greatest interest for the initial drive shot. It is this shot, which provides the greatest level of satisfaction when well hit and which has the most deleterious effect when badly hit. It receives far more attention and practice off the course than its relative frequency would otherwise warrant.

The drive shot retains an element of intrigue for most players because its dynamic characteristics are beyond the normal range of human perception. The transfer of energy to the ball is so rapid that the ball has departed far from the tee before the player can register the impact either by feel or sight. For example, in a well hit golf drive shot the ball and club face are typically in contact for only about 0.45 ms, during which time the ball moves about 15 mm to 20 mm, and the average force between the ball and club face is around 12,000 N to 13,000 N. The ball departs from the club face at a speed of about 65 m/s. The ball also acquires significant spin motion from the driving shot, typically acquiring a back spin about a horizontal axis of around 3,500 rpm but no significant spin in the direction of travel of the ball. The ball may also acquire a side spin component about a vertical axis, which when combined with its back spin, causes a resultant spin about an axis tilted in a plane which is perpendicular to the direction of travel of the ball. The side spin component is not always present and its magnitude is typically less than a few percent of that of the back spin component on well hit drive shots. During impact, typically about 39% of the club head energy is transferred to the ball, about 8% is lost

and about 53% is retained in the club head. Usually, over 99% of the ball's energy is acquired as linear kinetic energy, with spin energy accounting for less than 1%.

The prior art has produced various means whereby the initial drive shot can be carried out away from the golf course to allow player practice or to permit measurement of the characteristics of the drive shot.

The most common means for player practice is the dedicated driving range. Players are positioned in a row, are each supplied with a quantity of balls and drive the balls from a tee piece out across the practice range. The range is usually several hundred meters long and is supplied with markers which indicate the distance from the driving position. Typically, the range is outdoors and the player position is under cover.

Although the dedicated driving practice range is of great benefit to the player, it suffers from several disadvantages. There is usually far more noise and distraction that would occur during normal golfing play. It may be very difficult for the player to see or judge the shot or to discriminate his or her ball, since other players are simultaneously hitting balls, the balls can be very far distant and there can be many stationary balls lying on the range. Also, ranges tend to use old balls with a dull surface. Furthermore, the location of the range may be inconveniently distant from the player and there may be uncertainty as to whether space will be available when the player arrives. In addition, the range may not be playable in poor light or inclement weather. The driving practice range also has several inherent disadvantages. One inherent disadvantage is that there is no automatic method for statistically measuring performance. Another is that the player cannot maintain his or her stance between shots because of the necessity to look up and follow the progress of the ball.

The prior art has attempted to overcome some of the disadvantages of the dedicated driving range by providing a practice or measurement means in a more convenient location such as the player's own home or at a location where golf instruction is given or where golf equipment is fitted or matched to the player. The most successful of these alternatives to the practice driving range appear to be those which allow the player to hit a ball into a large net or screen and which

measure the speed and direction of the ball in flight using remote sensors such as electromagnetic wave emitters and receivers. Although they have overcome some of the disadvantages of the driving range, they have achieved very limited success due to several drawbacks. They are very expensive and require a large amount of space to set up. They are not readily portable and many are not suitable for outdoor use. They usually require a substantial electrical power source. They typically do not measure certain important characteristics of ball flight, such as back spin and side spin and in consequence cannot accurately predict the free flight trajectory of the ball.

The prior art has also proposed various alternatives to the practice driving range where the ball is connected or tethered to an apparatus. However, none of these alternatives appears to provide a satisfactory solution. Some simply do not adequately simulate a real practice shot. Those which have attempted to provide adequate or accurate details of the characteristics of the flight of the ball appear to be impractical and to display a failure to appreciate the mechanics of the golf drive shot.

It is accordingly an object of the present invention to provide a method and apparatus which measures the flight characteristics of a ball, such as a golf ball, which has been struck by a moving implement or other object, such as a golf club, and/or which permits player practice in striking the ball, and which overcomes some or all of the disadvantages associated with the prior art methods and apparatus.

SUMMARY OF THE INVENTION

The present invention provides a method for measuring the motion characteristics of a ball when struck by an object, which involves connecting the ball such that the connected ball undergoes motion characteristics which replicate some or all of the motion characteristics of an unconnected ball over a distance sufficient to replicate such motion characteristics, and which is of sufficient duration that the motion characteristics of the ball can be determined by

measurement of motion characteristics of the connection means or by other measurement means.

The invention also provides an apparatus which comprises a connected ball, a connection means and a measurement means, where the connection means is operable to allow the connected ball, when struck by an object, to replicate some or all of the motion characteristics of an unconnected ball, over a distance sufficient to replicate such motion characteristics, and where the measurement means is operable to measure the motion characteristics of the connected ball.

The method and apparatus are applicable to a golf ball which receives an impact from a golf club and where the motion characteristics of the ball relate to the initial launch flight characteristics of the ball.

Throughout the specification, where the method or apparatus refers to the game of golf, an apparatus is described which is suited to players who strike the ball to the left, as would normally be the case for right handed golfers. A mirror image arrangement, similar in other respects, can be used for players who strike the ball to the right.

In a preferred embodiment of the invention, the connection means provides three degrees of freedom to the connected ball over a distance sufficient to replicate the motion of an unconnected ball, such that within the limits of this movement, the connection means is in a unique geometric arrangement for each possible position of the ball.

In a preferred arrangement of this embodiment, the connection means comprises three pivot joints, each capable of partial rotation in one plane, with each joint connected in series between the ball and the body of the apparatus and with an interconnected member between each of the components in series. Two of the pivot joints allow partial rotation in a substantially horizontal plane and the other pivot joint allows partial rotation in a substantially vertical plane. The ball is free to move freely in three-dimensional space over the limited region where each pivot joint has its interconnected members at an angle which is less than 180° and where the pivot joints

remain capable of further rotation. The characteristics of motion are measured while the ball remains in this region. Since within the limits of such movement, each of the pivot joints and interconnecting members is in a unique position for each possible position of the ball, the flight characteristics of the ball can be determined by measuring the relative positions or angles of the pivot joints or interconnecting members.

The three degrees of freedom may also be provided by alternative arrangements. For example, they may be provided by a connection means comprising two pivot joints, each capable of partial rotation in one plane, and one linear sliding joint. Each joint, along with interconnected members as appropriate, is connected in series between the ball and the body of the apparatus. The sliding joint allows partial extension or retraction of the distance between the ball and the pivot joint nearest the ball. The pivot joint nearest the ball allows partial rotation in a substantially vertical plane and the other pivot joint allows partial rotation in a substantially horizontal plane. The ball is free to move freely in three-dimensional space provided the sliding joint remains capable of further movement and each pivot joint has its interconnected members at an angle which is less than 180° and where the pivot joints remain capable of further rotation. The characteristics of motion are measured while the ball remains in this region where it is free to move in three-dimensional space.

As discussed later, the loft angle of the ball in a drive shot can be estimated from knowledge of the ball speed and back spin. It is therefore possible to determine the unique position of the ball with knowledge of the positions of just the two pivots which allow rotation in a horizontal plane. Accordingly, the angle of direction of the shot can be determined by measuring the angles of these two pivots when the ball is in substantially free flight.

Reference is now made to Figure 1, Figure 2 and Figure 3, which show an application of the preferred embodiment projected onto the horizontal plane. In each of the figures, the solid lines represent the interconnecting members between the pivots at different positions of the ball. The broad dashed line CLM represent the flight path of the ball, with straight line movement along CL and orbital movement along LM. Point C represents the starting position of the centre of the

ball. In the starting position, point A represents a pivot which allows movement in a substantially horizontal plane between interconnecting member AB and the body of the apparatus, and point B represents a pivot which allows movement in a substantially horizontal plane between interconnecting members AB and BC. Line CE represents the direction of travel of a ball which is hit straight. Line CF represents a selected maximum allowable deviation in the direction of travel of a ball hit to the right and line CD represents a selected maximum allowable deviation in the direction of travel of a ball hit to the left. The apparatus is also provided with a pivot which allows movement in a vertical plane, which is not shown in the figures.

Figure 1 shows the arrangement where the ball is hit straight along its intended line of direction. The starting position is arranged such that the angle of pivot B, <ABC, is less than 90°, and the straight shot direction is taken as the direction parallel to AB. Accordingly, the ball will travel along path CE if a straight shot is taken, where CE is parallel to AB.

The apparatus is operable to accurately measure the direction of shots over the angle range <DCE, where shots are to the left of centre and over the angle <FCE where shots are to the right of centre.

The apparatus is operable to measure the angle of each of the two pivots which allow rotation in a horizontal plane. The apparatus monitors these angles as the shot progresses, where the ball is substantially moving in free flight, and determines the angle of direction. For example, if a straight shot is taken, the angle at A will have the same magnitude at the start of the shot as it will when the ball has reached position J, where J is such that JB and CB are at the same magnitude of angle to a line from B which is perpendicular to AH. Any movement of the angle at A clockwise or counter-clockwise will indicate that the ball travelled to the right or to the left of the straight shot direction, respectively.

Figure 2 shows the same arrangement but where the ball travels to the right of center along direction CF. The interconnecting member rotates from its starting position at AB, to a

maximum clockwise position at AP, where PQ is perpendicular to the line of ball movement CL, and then moves counter-clockwise to the position AK. Any simultaneous measurement of the angles at both pivots, while the ball is travelling along the straight line path CL, will be sufficient to determine the angle of direction of flight <FCE by trigonometric calculation.

Figure 3 again shows the same arrangement but where the ball travels to the left of center along direction CD. The interconnecting member rotates counter-clockwise from its starting position at AB to the position AK. Any simultaneous measurement of the angles at both pivots, while the ball is travelling along the straight line path CL, will be sufficient to determine the angle of direction of flight <DCE by trigonometric calculation.

In relation to the measurement of a ball travelling to the left of centre, particular care should be taken in the arrangement of the apparatus to avoid the flight of the ball being too abruptly pulled into radial orbit about the first pivot, since the change is not tangential. The allowed movement counter-clockwise at pivot A should be limited to cause a less abrupt change from straight line flight to the radial flight. However, this limitation must not be such that it provides insufficient distance of straight line flight for measurement of the motion characteristics to be taken. In the case of a driven golf shot, the measurement should be taken after the ball is released from contact with the club face, which will occur approximately 15-20 mm from its initial starting position, as mentioned earlier.

Since the position of the ball can be determined at two points on its straight line movement, the distance between those points can be readily determined by trigonometric calculation. If the time is recorded at which the ball traverses the two points, its speed can be determined by dividing the distance by the time duration, which is the difference between the two recorded times.

Alternatively, the magnitude of ball speed may be measured when the ball is in radial orbit about the first or the second pivot, since its kinetic energy and non-directional speed magnitude remain substantially unaltered when its flight is pulled from straight line into orbital flight.

The motion characteristics measured by the method of the invention also include the spin of the ball about an axis through the ball. This aspect of the invention provides a method for calculation of the spin of the ball about its natural spin axis, which would occur if the ball was unconnected, by measurement of the spin of the ball about different axes passing through the ball, and includes connecting the ball such that it is free to spin about these different axes, and setting the connection to provide these different axes at successive strikes of the ball. In the preferred embodiment, the apparatus comprises a spin means which is operable to allow the ball rotate about an axis while connected to the apparatus. The apparatus is operable to measure the speed of rotation and to vary the angle of inclination of the axis about which the ball rotates. The apparatus is also operable to compute the relative components of back spin and side spin by analysis of the speeds of rotation at different angles of inclination of the axis.

When a free ball is struck unevenly by a flat surface, such as when a golf ball is struck by a golf club, a rotational motion may be transmitted to the ball. In the case of a golf ball being perfectly struck by a club such as a driver, the lofted club face imparts a significant back spin to the ball, causing it to rotate about a horizontal axis. If the ball is unevenly struck, as frequently occurs, an additional component of side spin is imparted and the ball rotates about a resultant axis which is inclined to the horizontal and which is frequently understood by golf players in relation of its back spin and side spin components. In practice, over the common ranges of golf ball shots struck with driver or low wood clubs, the axis of rotation is within an angle of about ±10° to the horizontal, the direction of slope depending on the rotational direction the component of side spin. Side spin is important in the game of golf because it can cause significant lateral movement during the flight of the ball. If the resultant axis is tilted down to the right, the ball will drift to the right during flight displaying what is commonly called 'slice' or 'fade' for right handed players, depending on whether the motion is unintentional or intentional, respectively. Tilting down to the left will result in the ball drifting to the left during flight, displaying what is commonly called 'hook' or 'draw' for right handed players, again depending on whether the motion is unintentional or intentional, respectively. The directions are reversed for left handed players.

The method of the invention relates to an observation that when spin is limited to rotation about a specific fixed axis, a golf ball will spin about this fixed axis with a spin value which is substantially equal to that which the component of its free or unconnected spin would be, if appropriately projected onto the specific fixed axis. According to the invention, the appropriate projection is the projection of a spin vector, perpendicular to the axis of free spin, onto a perpendicular to the specific fixed axis of spin. Since the spin axis is known to lie in a plane which is perpendicular to the direction of flight of the ball, the projection will lie in this plane.

This is illustrated by the example of a ball which is free to rotate about any axis and which when struck assumes a spin with a magnitude of S about its axis of free spin, which is at an angle of α to a fixed reference axis, such as the horizontal. If this same ball is struck in the same manner, but its axis of rotation is fixed at θ to the fixed reference axis, then the magnitude of its spin will be $S_\theta = S.\cos\theta$. If the ball is similarly struck at two different fixed angles, $\theta 1$ and $\theta 2$, the values of which are known, two values of spin magnitude $S_{\theta 1}$ and $S_{\theta 2}$ will result, which if measured will be sufficient to determine values for S and α.

In the preferred embodiment, two fixed axes are used, which are tilted at angles of equal magnitude in opposite directions relative to the horizontal.

Reference is now made to Figure 4 and Figure 5, which refer to an embodiment with two fixed axes tilted at angles β, to the horizontal, one clockwise and the other counterclockwise to it. Lines AF, AE and AG represent perpendiculars to the horizontal, to the fixed axis tilted to the left and the fixed axis tilted to the right, respectively. Line AB represents the spin vector and is of length proportional to the magnitude of rotation of free spin, S. It is perpendicular to the axis of free spin and is at an angle of ϕ to the perpendicular to the horizontal, AF, and θ to the perpendicular to the fixed axis which is tilted to the right, AG.

Figure 4 relates to the situation where the axis of free spin is at a smaller angle to the horizontal than the angle of the fixed axis. This results in the spin vector AB being between lines AF and AG. A shot which would result in spin vector AB, when allowed free spin, will result in the

projected vector AD where spin is limited to the fixed axis perpendicular to AD. Line BD is perpendicular to line AG. Similarly, it will result in vector AC where spin is limited to the fixed axis perpendicular to AC. Line BC is perpendicular to line AE. Since $\theta = (\beta - \phi)$ and AB = S, simple trigonometry yields

AD = S.cos($\beta - \phi$) and AC = S.cos($\beta + \phi$), where AD and AC are the measured magnitudes of spin about the two fixed axes.

Figure 5 is similar to Figure 4, but shows a shot where the angle of the spin axis is at a greater tilt angle than either of the fixed axes. In this instance, $\theta = (\phi - \beta)$, <CAB = $(\beta + \phi)$ and again AB = S. Simple trigonometry yields, AD = S.cos($\phi - \beta$) and AC = S.cos($\beta + \phi$). If absolute values of magnitude are used and due account is taken of whether values are positive or negative, cos($\beta - \phi$) may be substituted for cos($\phi - \beta$), whereupon the relationships are the same as those relating to Figure 4.

When the values of the free spin vector S and ϕ are determined, the magnitude of its components can be determined, since back spin = S.cosϕ and side spin = S.sinϕ.

If the two measured values, AD and AC, are found equal, this indicates that side spin is absent. If the value of AC is found to be greater than AD, this indicates that the spin axis is tilted down to the left and the result is a hooked or draw shot. If the value of AC is found to be less than AD, this indicates that the spin axis is tilted down to the right and the result is a sliced or fade shot. The values of measured spin about the two fixed axes may be processed by the apparatus as trigonometric functions, as indicated above. Alternatively, they may be processed by comparing the relative magnitudes of the two values, since there is a unique relationship between the tilt angle of the axis of spin ϕ and the ratio of the spin values about the two fixed spin axes for any given value of β.

Various fixed axes angles β may be successfully used in the apparatus. However, increases in this angle will cause the apparatus to become proportionately more sensitive to the measurement of the side spin component and less sensitive to the measurement of back spin

component. Increases in the angle are advantageous because the former component is invariably much smaller in magnitude than the latter and is more difficult to measure. It also has the advantage that it will reduce the proportional masking influence of any variations in the back spin component over successive shots. The proportional influence of the fixed axes angle β can be seen from consideration of its two extreme values. Where β has the extreme value 0°, the apparatus will directly measure the back spin component and will not measure the side spin component at all. Similarly, where β has the extreme value 90°, the apparatus will directly measure the side spin component and will not measure the back spin component at all.

When a golf ball is struck in a drive shot, its rate of back spin is very close to being directly related to its speed and its loft angle. For a given speed and set of conditions, back spin and loft angle substantially follow a unique relationship. Accordingly, it is possible to make a close estimate of loft angle from a knowledge of ball speed and back spin under the known conditions which apply on the apparatus of the invention, and it is usually unnecessary to make a separate measurement. Alternatively, the loft angle may be determined by measuring the angle of the pivot which allows rotation in a vertical plane. The measurement should be taken when the ball is describing straight line flight because the loft angle will be altered by the restraining force of the arm when the ball is pulled into orbit about the pivots.

The measurements of angle of direction and ball speed may be influenced by loft angle because the effective length of the member connecting the ball to the pivot, which allows rotation in the vertical plane and henceforth referred to as the vertical pivot, when projected onto the horizontal plane, will change as the ball gains elevation, and this gain in elevation is influenced by the loft angle. The projected length will be the product of the actual length multiplied by the cosine of the angle of the vertical pivot relative to the horizontal. Over the initial period when the ball is in straight line flight, the vertical pivot angle, relative to the horizontal, is very small, ranging up to about 4°, where the apparatus has dimensions similar to those described in the preferred embodiment. Since the cosine of 4° is approximately 0.9976, the effect of loft angle is not significant and may be disregarded. If measurements are taken where the elevation of the ball is much more significant, due allowance may be made for the effective change in the

projected length of the members in the horizontal plane. When straight line flight changes to orbital flight, the orbital path is substantially an inclined curved arc which reaches its highest point after about 90° of rotation and then gradually descends.

Measurement of the various motion characteristics presents potential difficulties when related to the severe conditions which arise, for example, when a golf ball is struck by a golf club in a drive shot. One of these relates to the shock conditions created by the impact between the ball and club face, where the forces and rates of acceleration are very high. Any parts directly influenced by the motion of the ball may also be subjected to these shock conditions with very high rates of acceleration and consequent high inertia forces. If appropriate precautions are not taken, these may result in interference with the accurate measurement of the characteristics or damage to the measurement means. Further potential difficulties relate to the very fast response which is required due to the high speed of the ball following the impact and to the small distances or angles to be measured.

In the preferred embodiment, measurement is carried out by one or more sensing means which operate in cooperation with a controller means.

The sensing means comprises a target with irregularities and a light, or other form of electromagnetic radiation beam, sensor. The target is located on the portion of the apparatus which endures the greater degree of shock or acceleration and the sensor is located on the portion which endures the lesser degree of shock or acceleration. The target is arranged as a relatively simple passive component which is operable to withstand high levels of shock or inertia forces. The sensor is operable to detect the presence or absence of the irregularities, which may comprise slots or holes, by interruption of a light beam, and thereby detect motion of the target relative to the sensor. The light beam signal is generated from and reconverted to an electronic signal, by suitable electronic devices such as a light emitting diode and a photo diode, respectively, and these in turn communicate with a controller, such as a programmed electronic processor, where the electronic signals are processed as required. The sensor comprises a light optical emitter and a light optical receiver which are held in a spaced apart

relationship and are operable to pass a light beam across a gap between them. The target irregularities are passed through the gap and interrupt the light beam. The sensing means has the advantage that shock forces can be reduced at the sensor because physical contact is not made between the target and the sensor.

A reduced level of shock will usually still occur at the sensor, due to it being transmitted through the joint of the connecting means. The sensor may also still be subject to some degree of rapid acceleration because it may lie between the ball and one of the other joints of the connecting means. This shock and acceleration is isolated from the electronic components of the invention by arranging the optical signals to be communicated between the optical emitter and receiver and the electronic devices by means of flexible optical fibres. The electronic devices may be mounted in a stationary position away from all significant shock forces.

The use of optical devices, directly connected to the region where the electronic controller and devices are located, is also advantageous in producing a very rapid response. The signal reaches the electronic system at the speed of light and is then processed by very high speed electronics. The direct communication avoids the need for other electronic devices, such as remote amplifiers, which could cause significant response delays.

In a further refinement of the preferred embodiment, the controller is provided with timing means which are operable to measure the time duration between two events which are directly or indirectly related to the signals received from the sensors. This allows fine resolution of the measurement of motion of the target irregularities relative to the sensors. The measurement of motion is not limited to the relatively coarse resolution of the number of irregularities passing the sensor between two identified events, but rather the fine resolution of the length of time elapsed between two identified events, where these identified events may relate to the detection of individual irregularities.

The controller may register signals at a consistent specific point in the signal cycle, such as when the optical signal switches on or when it switches off. This has the advantage of having greater repeatability accuracy since there may be unpredictable variations in the duration of the

on and off stages of the cycle. Alternatively, the controller may register changes of state, such that each on or off is detected as a signal. This has the advantage of providing twice the number of signals, but with some loss of repeatability accuracy.

The sensing means may be provided with an adjustment means which is operable to adjust the relative distance between the target and the sensor in the direction of normal relative movement between them. The adjustment means may comprise a screw adjustment used to position the sensor relative to its base and a means for locking the sensor in the screw adjusted position, such as by use of lock nuts on a screw position or by use of fasteners in elongated slotted holes.

The apparatus may typically be required to measure small movements over very short periods of time, for example ball movements of about 35 mm occurring within about 0.500 ms. Care must be taken with the method of measurement and the construction of the apparatus to ensure high accuracy in the results.

In the preferred embodiment, the target irregularities comprise a rotary vane with open or closed radial slots. The vane may be capable of limited rotation or of continuous rotation, depending on the type of motion characteristics which are being measured. As the vane rotates, the light beam will traverse a locus along the vane and crossing the slots and interstitial regions to provide a series of ON and OFF signals to the light sensor.

In the measurement of certain motion characteristics, the locus of the vane may travel as little as 5-6 mm through the sensor. The vane spacing is minimised within the design constraints of the apparatus to allow the measurement to be taken over the longest distance within the locus being measured. For example, if the length to be measured is 5 mm and the combined slot width is 3 mm, that is the combined width of the slot gap and the interstitial region, the apparatus would only be capable of providing data over one combined 3 mm slot width, whereas if the combined slot width is 2 mm, it could advantageously provide data over a measurement of two combined slot widths or 4 mm.

In the preferred embodiment, pairs of measurements which result in the determination of an interval of time between two events, are each taken either at the start or at the end of the signal. Also, with some or all of the sensors, the apparatus is operable to record data both at the start and at the end of the signal and is operable to select a set of measurements from either the start or the end, depending on which set measurements covers the longest distance. The importance of this capability is illustrated by the following example. If the length to be measured is 5 mm, the combined width of the slot gap and the interstitial region is 2 mm and the optic beam has just passed the slot gap when the measurement commences, then the apparatus will register two slots where it takes the measurements at the end of the signal but will only register one slot where it takes the measurement at the beginning of the signal.

In the preferred embodiment, the vane is also of a type which can be constructed with high dimensional accuracy in the spacing of the slots along the locus of the optic path. For example, the vane may be constructed from thin stainless steel material produced with a dimensional accuracy of ± 0.02 mm or better on the required dimensions. This level of accuracy can be economically produced by high precision press work, laser cutting or chemical machining. The vane material may be supported by material which is set back from the edges of the vane slot and which does not interfere with the operation of the optic sensor.

In the preferred embodiment, the optic sensor electronic components have very fast switching time characteristics and are directly connected to the electronic processing components of the controller. Plastic fibre optic photodiode detectors are available with photocurrent rise and fall times of 0.0001 ms. These components can be obtained at economic cost and can be directly mounted onto electronic components or circuit boards.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION.

The invention will now be described more particularly with reference to the accompanying drawings in Figure 6 to Figure 14 which show, by way of example only, two embodiments of

the invention which are suitable as an apparatus which measures the flight characteristics of a golf ball which has been struck by a golf club in a drive shot.

In the drawings:

Figure 6 shows a plan view of the mechanism of an apparatus which measures the flight characteristics of a golf ball which has been struck by a golf club in a drive shot. The mechanism includes an actuator means and a controller, which are not shown in the drawing.

Figure 7 shows an end view of the mechanism shown in Figure 6.

Figure 8 shows a side view of the mechanism shown in Figure 6.

Figure 9 shows a sectional side view of part of the mechanism shown in Figure 6.

Figure 10 shows a sectional side view of the ball and arm shaft, which form part of the mechanism shown in Figure 6.

Figure 11 shows a plan view of the mechanism shown in Figure 6, positioned within a housing. For clarity, the housing is shown represented by a transparent outline. Buffers and a retardation means are also shown.

Figure 12 shows a side view of the mechanism shown in Figure 6, positioned within a housing, again represented by a transparent outline. The mechanism is shown in the raised position with the arm tilted down towards the ball. The dashed line represents the tee height of the ball.

Figure 13 shows a view similar to Figure 12, but with the mechanism shown in the lowered position with the arm tilted up towards the ball. The dashed line again represents the tee height of the ball.

Figure 14 shows a side view of the ball and arm of an alternative embodiment, which is similar to that shown in Figure 6, but where the tilt axis is varied by rotation of the arm. The arm and its components are shown in section and the position of a sensor head, which lies behind the section, is shown by a dashed line.

The following is an index of the reference numerals used in the drawings:

1. Ball.
2. Polymer anchor.
3. Arm
4. Outer arm shaft.
5. Outer arm shaft threaded section.
6. Inner arm shaft.
7. Inner arm shaft shoulder.
8. Outer arm casing.
9. Inner arm casing.
10. Hole for inner arm shaft holding means.
11. Thrust bearing.
12. Ball rotation sensor vane.
13. Ball rotation sensor head.
14. Vertical-pivot.
15. Vertical-pivot shaft.
16. Vertical-pivot spring stop means.
17. Tilt support member.
18. Horizontal-pivot.
19. Horizontal-pivot shaft.
20. Horizontal-pivot block.
21. Horizontal-pivot returning means.
22. Horizontal-pivot sensor vane.
23. Horizontal-pivot sensor head.
24. Arm stop.
25. Supplemental-pivot.
26. Supplemental-pivot shaft.
27. Supplemental-pivot sensor vane.
28. Supplemental-pivot sensor head.
29. Upper stub arm.
30. Lower stub arm.
31. Centering means.
32. Stronger torsion spring.
33. Weaker torsion spring.
34. Rotational member.
35. Outer supporting frame.
36. Frame shaft.
37. Frame arm.

38. Inner supporting frame.
39. Ball retarding means shown in the home position.
40. Ball retarding arm.
41. Ball retarding arm pivot.
42. Ball retarding arm contact pad.
43. Ball retarding means shown in the end position.
44. Housing.
45. Housing front opening.
46. Club buffer.
47. Ball buffer.
48. Ball buffer deflecting surface.
49. Dashed line representing tee height.
50. Tilt-rotation shaft.
51. Tilt-rotation bearing.
52. Drive track
53. Clevis end.
54. Split collar and clip.

In overview, the ball is connected to the body of the apparatus by an arm which is connected in series to a vertical pivot, a horizontal pivot and a supplemental pivot. The ball and arm are free to rotate about the arm axis. The vertical pivot allows movement in a vertical plane and the horizontal and supplemental pivots allow movement in a horizontal plane. The three pivots allow straight line movement of the ball for a short distance when hit from the start position. The rotational position of the ball and the positions of the horizontal and supplemental pivots are monitored and recorded by light sensors operating in conjunction with a controller. The mechanism is protected within a housing and is operable to automatically change the tilt angle of the ball rotational axis over alternate shots without changing the tee height of the ball.

Referring now to specific parts of the apparatus, the ball comprises a real or simulated golf ball attached to an arm. It is of the solid type with an exterior which is resistant to wear or cutting. It may comprise one material throughout or may comprise a cover and concentric layers of different materials. Preferably it is of the type which produces high spin rates. For example, it may comprise a relatively hard centre and relatively soft outer layer. The combination of a hard centre and soft outer layer is used to promote high spin rates. The use of a hard centre also facilitates the use of a relatively inflexible shaft connection running through the ball centre because there is a reduced tendency for relative movement between the shaft and the ball material which might weaken the bonded connection. Also, the relatively inflexible shaft

interferes less with the natural performance of the ball. Preferably the ball material or construction is compounded to have a lesser coefficient of restitution than a typical golf ball used for normal play, the reduction being arranged such that the momentum transfer to the ball and connecting arm is made similar to that which would be transferred to a typical unconnected golf ball in normal play. The reduction has several advantages. It allows the impact to feel the same to the player as would the impact of a ball in normal play. It reduces the forces on the apparatus. The apparatus is programmed to compensate in an appropriate manner for any changes in the motion characteristics. Preferably any materials used in the construction of the golf ball do not comprise fillers of the type which are frequently used to increase the density of the ball but which are not otherwise necessary.

In an alternative arrangement, the ball is comprised of a hollow metal sphere. Such a ball may, for example, be constructed from stainless steel and comprise dimples to simulate a conventional golf ball. The arm passes though the ball and connects at both sides for added strength. The weight of the hollow ball and the connecting arm are ideally arranged such that their combined inertia is substantially the same as a conventional free golf ball. The wall thickness and wall thickness distribution of the ball may be varied to provide a resilience which presents playing characteristics similar to a conventional golf ball. The weight of the shaft connection may be varied to provide an overall required weight. A connected ball of this type may provide advantages of strength, durability and safety over a more conventional connected golf ball.

The arm is connected to the ball by an arm shaft, which comprises an outer arm shaft and an inner arm shaft. The outer arm shaft is directly connected to the ball. The arm shaft is made from a high strength material such as a high strength grade of steel which is suitable for machining. The arm shaft is securely connected to the ball and is arranged such that it does not unduly influence the performance of the ball when struck.

The distal end of the arm shaft is provided with irregularities to facilitate a secure connection to the ball. These irregularities may comprise annular rims and grooves such as those shown in Figure 10. Irregularities of this type can be readily produced by machining a shaft which is

initially cylindrical. A polymer anchor is moulded onto the distal end of the shaft, prior to its attachment to the ball. Alternatively, the polymer anchor may be moulded in two halves and bonded onto the distal end of the shaft. Where the irregularities in the shaft comprise circular rims and grooves which are coaxial with the shaft, additional irregularities may be provided to prevent relative rotation between the anchor and the shaft. Such irregularities may comprise knurling or deforming the rims or using shaft material which is not circular in cross section. The particular polymer used in the anchor is of a type which is capable of being strongly bonded to the material of the ball. For example, it may comprise a polymer which is the same or similar to that used in the ball. The outer surface of the anchor is in the form of a frustum of a cone with a very shallow taper. The narrow end of this surface terminates in a coaxial cone with a very steep angle or taper corresponding to the shape suitable for the leading face of a milling cutter. A hole is machined in the ball using a rotary milling tool which produces a tapered hole which matches the external shape of the anchor. Suitable adhesive is added to the mating surfaces, the two parts are assembled and bonded together. The tapered frustum shape allows the adhesive to remain on the surfaces as the parts are being assembled and allows pressure to be evenly applied to the joint when the parts are brought together. The steeply angled end facilitates machining of the hole. Depending on the materials to be bonded and the adhesive used, the surfaces may require surface preparation. Chemically treating or machining the surface of the anchor and using it with a newly machined hole will usually satisfy any such requirements.

Alternatively, the hole may be machined fully through the ball, and the matching tapers on the hole and the anchor arranged in a reverse manner to that shown in the Figure 10. This has the relative advantage that the anchor is mechanically prevented from pulling out of the hole and is not solely dependant on the adhesive bond. It has the relative disadvantages that the reversed taper causes the size of the anchor to increase and the through hole reduces the strength of the ball by penetrating the original cover and layers on two sides of the ball.

The diameter of the outer arm shaft, where it exits the ball, is arranged sufficiently large such that it provides sufficient strength to enable it to withstand the considerable stresses which arise when the ball is struck by the club head. The cross section of the shaft is reduced a short distance away from the connection to the ball, where the stresses are far less than those adjacent

the connection to the ball. The outer arm shaft terminates in a threaded section which connects to a corresponding threaded section on the inner arm shaft, one of the threaded sections being external and the other being internal. The thread form is arranged such that the normal tendency of the ball to back-spin causes the threaded joint to tighten. A right hand thread is used on arm shafts suitable for right handed players. A left hand thread is used on arm shafts for left handed players, where the geometry shown in the figures is reversed. The outer arm shaft comprises an external thread at its end which is furthest from the ball. It also comprises a reduced cross section achieved by reducing the diameter along part of its length. The cross section is reduced to lessen its weight and inertia. Alternatively, it may comprise an internal thread and a reduced cross section achieved by providing a shaft which is hollow where the reduced cross section is required. The hollow section may be produced, for example, by using tubular material and plugging the ball end with a grooved component suitable for the attachment to the ball anchor, with a stem that extends through and fills the tube where the full cross section is required. The internal thread may be produced on the inside surface of the tube. The remaining hollow section may be filled with a less dense material to increase its strength to weight characteristics, if required.

The arm shaft is arranged such that it and the connected ball are free to rotate about their common axis. The arm shaft is supported by an arm casing which comprises an outer arm casing and an inner arm casing. Preferably the arm casing is produced from a light weight material such as a polymer or reinforced composite polymer. This lessens its weight and inertia and can be economically moulded to the required shape. Clearance is provided between the arm casing and the arm shaft to allow free rotation. Preferably this clearance is such that the arm casing can act as an effective bearing surface for the rotating shaft. Although the primary purpose for providing free rotation of the ball is to allow the ball to simulate the spin rotation which occurs with an unconnected ball, the freedom to rotate also reduces stresses which might otherwise damage the structure of the ball and its connection to the arm. It also provides a varying surface on which the ball is struck, thereby spreading wear and increasing the longevity of the ball.

Preferably the arm casing comprises two separate parts to facilitate ready replacement of the outer arm casing should this be inadvertently damaged by contact with the club head. The inner arm shaft comprises a shoulder which bears against a thrust bearing which is supported within a pocket in the inner arm casing. The thrust bearing prevents the arm shaft from withdrawing from the arm casing, yet allows the arm shaft to rotate with little friction. The inner arm shaft is provided with holding means for manually preventing its rotation to allow the outer arm shaft be screwed on or off by manually turning the connected ball. The holding means may comprise a radial hole through the inner arm shaft which can be aligned with corresponding radial holes in the inner arm casing. Insertion of a rod through the aligned holes will prevent rotation of the inner arm shaft relative to the arm inner casing. This will allow an end user to readily replace the ball and outer arm shaft assembly where the existing one is damaged or worn or where a ball with different characteristics is required.

The arm is provided with a ball rotation sensing means to detect the relative rotation of the arm shaft and ball within the arm casing. The sensing means comprises a vane disk with irregularities mounted on the arm shaft and a sensor head mounted on the arm casing. The sensor head detects the passing of the irregularities when the arm shaft rotates and communicates this to a computing and controlling device, henceforth referred to as the controller. The irregularities comprise radial open or closed slots around the circumference of the vane. The vane is securely connected to the inner arm shaft at a position near the end of the inner arm shaft which is furthest from the ball. The sensor head comprises a throated optical sensor head with an emitter lens and receiver lens transmitting a narrow light beam from one to the other. The vane is positioned such that one of its edges passes through the throat of the sensor head. The slot gaps on the vane allow the passage of the light beam and the interstitial regions interrupt the light beam. The light beam is communicated between the controller and the sensor head by means of flexible optical fibres, which are partly supported by the arm casing. The sensor means is located on the arm shaft at a position which is distant from the ball end. This has the advantage that the sensor is subject to far lower inertia forces resulting from the rotation of the arm about the main pivot or loft pivot than it would have if it were located near the ball end of the arm. The controller monitors the resulting optical pulses following the impact between the ball and club head. The controller measures the amount of time elapsed

during the passage of two or more of these pulses and thus calculates the speed of rotation of the arm shaft and ball.

The arm is connected to the apparatus by a pivot, henceforth referred to as the vertical-pivot, which allows relative rotational movement in a vertical plane between the arm and the apparatus. The vertical-pivot has several functions. It allows the ball to assume a natural movement when struck and driven from the tee position, by providing a vertical component of movement. This provides one of the degrees of freedom necessary to allow the ball to follow its natural movement when struck. It additionally prevents damage to the device by allowing freedom for the ball to move up or down, particularly in the event of a badly hit ball which is hit too high or too low. It also allows the axis or rotation of the ball and arm to be set prior to the ball being struck.

In the described embodiment, the vertical-pivot comprises a clevis type pivot with a vertical-pivot shaft, with its axis oriented in a horizontal direction. The arm is connected to the vertical-pivot by two cheeks on either side of the inner arm casing which comprise horizontal holes which receive the ends of the vertical-pivot shaft. The vertical-pivot is connected to an adjoining component of the apparatus which is referred to as the horizontal-pivot block. An extension of the material of the horizontal-pivot block comprises a horizontal hole and receives the centre portion of the vertical-pivot shaft. Washers are positioned on the vertical-pivot shaft between the connecting parts of the arm casing and horizontal-pivot block and the shaft retained in position by means such as screws or cross pins or by providing stops on the vertical-pivot shaft ends.

The vertical-pivot is provided with a spring stop means which is operable to support the arm at a required rest angle, but which allows the arm to rotate downwards if the arm is subjected to a force which might otherwise damage it or another part of the apparatus. For example, it protects the arm from damage which might otherwise result from the ball being struck too high by the club head. The spring stop means does not restrict upward rotation of the arm above the rest angle. In the described embodiment, the spring stop means comprises a substantially flat spring, one end of which is fixed to the underside of the horizontal-pivot block and the other end of

which supports the arm by bearing against a bearing surface provided on its underside. The flat spring may be provided with a slightly profiled shape, such as a slightly convex shape elongated along the length of the spring as seen in plan view, which allows the spring to decrease its resistance to deformation when the deforming force exceeds a planned threshold. The threshold force causes the spring to temporarily buckle and allow the arm to rotate downwards. The spring retains sufficient force to subsequently return the arm to the unbuckled state against the resisting force of gravity.

The apparatus is operable to set the axis of rotation of the ball and arm at different angles prior to the shot. The purpose of this is to provide a means for determining the relative components of horizontal and vertical spin, as would have occurred if the ball had been free or unconnected, by comparing the rotation speeds of successive shots with the axis of rotation at different angles. The apparatus is also operable to retain the ball at the same vertical height from the ground or mat when the angle of the axis is changed. The purpose of this is to avoid any visual change in the starting position of the ball and to retain the same tee height between shots. In the preferred embodiments, the axis is alternately set at two angles, one with the axis tilted downwards from the ball, and the other with the axis tilted upwards from the ball. The two angles are of the same magnitude relative to the horizontal, but in opposite directions.

In the embodiment shown in Figures 6 to 13, henceforth referred to as the lifting-tilt embodiment, the downward angle is achieved by arranging the rest position of the vertical-pivot spring stop means such that at that position the axis of the arm and ball tilts downward from the ball at the required angle. The upward angle is achieved by arranging the apparatus to be operable to lower the vertical height of the vertical-pivot axis and by providing a tilt support member under the central region of the arm casing which bears against the arm casing and causes the ball end of the arm to tilt upwards as the vertical-pivot axis is lowered. Figure 12 shows a side view of the apparatus with the axis tilted upwards from the ball and Figure 13 shows it with the axis tilted downwards from the ball. The tilt support member is located sufficiently distant from the ball to prevent it being struck by the club during the shot.

In the lifting-tilt embodiment, the following precautions are taken to allow the arm to rotate counter-clockwise when returning to the starting position when the vertical-pivot axis is in the lower position. The contacting surface of the tilt support member or the arm is composed of a low friction material such as PTFE. The tilt support member either extends around the full arc of travel of the arm or is provided with a ramp which allows the arm to return to the starting position. The tilt support member is also provided with a spring stop means which is operable to support the member and the arm at the required height under normal operating conditions, but which allows the member to descend against the force of a spring if the arm is subjected to a force which might otherwise damage it or another part of the apparatus. In particular, it protects the arm from damage which might otherwise occur if it is inadvertently driven down by being struck too high by the club head. The tilt support member is also provided with an adjustment means which is not shown in the figures. This is operable to set the rest height of the tilt support to permit the height of the ball to be equalised for the two tilt positions of the axis. The means may conveniently comprise a screw adjustment and screw locking means.

In an alternative embodiment, henceforth referred to as the rotating-tilt embodiment, the alternating change in the angle of the axis of rotation is achieved by providing the arm with a joint, henceforth referred to as the tilt-rotation joint. This joint is operable to allow limited rotation of the ball and outer arm shaft, relative to the pivots, about an axis which if extended would pass through the centre of the ball, henceforth referred to as the tilt-rotation-axis. When the ball and outer arm shaft are rotated about this axis, the ball height remains unchanged. The arm is also arranged such that the axis of the ball and arm shaft lies at a fixed angle to the tilt rotation axis. In a preferred arrangement, the tilt-rotation joint is alternately rotated between two positions, one position having the arm shaft higher than the other position. In the preferred arrangement, the tilt-rotation joint also rotates through 180°, providing one position with the arm shaft above the tilt-rotation axis and the other with the arm shaft below the tilt-rotation axis. In the former position the arm shaft axis tilts down towards the ball and in the latter position the arm shaft axis tilts up away from the ball.

The apparatus is operable to automatically rotate the tilt-rotation joint by means which are external to the arm. In the preferred embodiment, the apparatus rotates the arm when the arm is in the home position between shots and rotation is imparted by one or more powered wheels or gears engaging a circumferential track or gear on the arm. In an alternative embodiment, the apparatus rotates the arm when it is returning to the home position after a shot and rotation is imparted by a track or toothed rack engaging a circumferential track on the arm.

Figure 14 shows an example of the rotating-tilt embodiment with a small clearance between the vane and tilt-rotation shaft. Other tilt angles can be provided by altering the geometric arrangement of the components. The arm and its components are similar in many respects to that in the earlier described tilt-lifting embodiment. The ball is connected to an outer and inner arm shaft. The arm shafts are joined with a threaded section and are provided with a shoulder and thrust bearing. The ball and arm shafts are free to rotate and rotation is detected by a sensor vane and sensor head. The arm shafts are supported by an outer arm casing. The inner arm shaft comprises a hole which provides a holding means for removal or replacement of the ball and outer arm shaft, although in this instance the hole is positioned on the ball side of the thrust bearing.

The tilt-rotation joint provides the connection between the arm and the vertical-pivot. The tilt-rotation joint comprises a clevis end, a tilt-rotation shaft and an inner arm casing. The clevis end forms part of the vertical-pivot. It comprises two or more cheeks which form a clevis to engage the vertical-pivot shaft, the clevis being similar in many respects to that in the earlier described tilt-lifting embodiment. The clevis end is provided with a hole through which the tilt-rotation shaft is mounted. The hole is coaxial with the tilt-rotation axis which passes through the centre of the ball and the centre of the vertical-pivot axis. The clevis end is also provided with a boss on the side facing the ball. A tilt-rotation bearing, such as an enclosed ball bearing, is mounted on the boss. The boss and the bearing are coaxial with the tilt-rotation axis. The clevis end comprises a polymer or reinforced polymer moulding. The vertical-pivot is provided with a spring stop means, which is not shown in the figure but is similar in function to that described in the lifting-tilt embodiment. It allows the vertical joint to pivot downwards if the ball is inadvertently hit downwards. However, in this instance the vertical-pivot joint is held horizontal

in the rest position. The preferred arrangement comprises a helical compression spring, pre-tensioned in a pocket or on a pin in either the clevis piece or horizontal-pivot block mouldings. The spring bears against a captive member which holds the vertical-pivot joint in the horizontal position and at the same time allows free upward rotation of the joint. The member and spring are depressed if the joint is subject to a downward force significantly greater that the normal gravity force exercised by the weight of the ball and arm. In alternative arrangements, the spring element is provided by a pre-tensioned torsion spring or a flat spring.

The inner arm casing connects to the outer arm casing, arm shafts and ball. It also comprises a polymer or reinforced polymer moulding. The inner arm casing is provided with a hole and cylindrical cavity, both coaxial with the tilt-rotation axis, to receive the tilt-rotation shaft and tilt-rotation bearing, respectively. The components are arranged such that the tilt-rotation shaft remains fixed in the hole in the clevis end but rotates freely in the hole in the inner casing. The tilt-rotation shaft is comprised of steel and is provided with a head on one end and a fastener on the other end. It serves several functions. It fastens the clevis end and inner arm casing together, resisting the significant centrifugal forces which occur during operation of the apparatus. It cooperates with the bearing to provide additional bearing support for the tilt-rotation joint. It provides additional rigidity and strength to the connection between the ball and vertical-pivot.

The inner arm casing also protects and supports the outer arm casing and thrust bearing, holding the ball and arm shaft axis at a fixed angle to the tilt-rotation axis. It also protects and supports the sensor head, which is positioned to one side of the tilt-rotation shaft and is located in a pocket in the inner arm casing. The inner arm casing and the clevis end are provided with irregularities, such as projections or indentations, which limit the relative rotation to 180°, by providing stops where the inner arm casing reaches its upper and lower positions. These are not shown in the figure. The inner arm casing is provided in two parts, to allow manufacture of the internal cavities and to allow assembly and disassembly of components located within the cavities. In a preferred arrangement, the two parts are held together by steel fasteners and a steel clip around a split collar which surrounds the inner arm shaft and tilt-rotation shaft. The collar and clip may, for example, comprise an elliptical or circular shape and the joint in the clip may

comprise abutting right angle outward bends in the clip, which are provided with holes and which are tightened and held together by threaded steel fasteners. In the preferred arrangement, the two assembled parts are also used to secure the outer arm casing. The outer arm casing is provided with an external rim on the end which fits within the inner arm casing. The inner arm casing is provided with two semi-cylindrical cavities with semi-cylindrical recesses corresponding to the rim. The end of the outer arm casing is firmly clamped in the inner arm casing when the two parts of the inner arm casing are fastened together.

The thrust bearing retains the arm shafts and vane in position and resists the significant centrifugal forces in an axial direction during the shot with little frictional restraint being imparted to the rotation of the arm shafts and vane. The thrust bearing is also of the type which provides bearing support in a radial direction. The vane comprises a thin stainless steel disk which is supported by the shoulder on the ball side of the inner arm shaft. The vane is supported by a flanged collar on the other side, with the flange providing support for the vane. The collar is provided with an elongated outer diameter and is coaxial with the inner arm shaft. It is fixed in position by means such as mechanical staking, bonding or an end threaded fastener. The vane may also be bonded to the shoulder and flange. A washer is provided on the collar and axial restraint in a direction away from the ball is provided by the flange and washer bearing against the inner arm casing.

The sensor head is mounted on the inner arm casing and connected by flexible optic fibres to the inner part of the arm, where tilt rotation does not occur. In the preferred arrangement, the tilt-rotation shaft is made from a hollow tube and the optic fibres are routed through the hole in its centre. The optic fibres are fixed in relation to the inner arm casing at one end and fixed in relation to the clevis end at the other end. The rotation of the joint is accommodated by ± 90° twisting of the optic fibres in the hole, where they are already laid in a slightly twisted or slack disposition. The optic fibres are directed into the end opening in the shaft by means such as a U shaped piece of rigid tube which is fixed relative to the inner arm and opens at one end into the hollow shaft which is fixed relative to the clevis piece. The optic fibres exit through an obliquely orientated hole adjacent the clevis end. The optic fibres, the U shaped piece of tube

and the exit hole are not shown in the figure. The end of the shaft adjacent the clevis end is provided with a square or hexagonal head which is located in a matching recess in the clevis end. This prevents any possibility of rotation of the tilt-rotation shaft relative to the clevis end.

In an alternative arrangement, the optic fibres do not pass through the shaft but are protected and supported within a looped flexible polymer tube, mounted outside the inner arm casing and clevis end, which changes little in shape when the arm rapidly accelerates during the shot. In other alternative arrangements, the sensor head is mounted on the clevis end. In one such arrangement, two sensor heads are provided, one corresponding to each of the two operating positions of the tilt-rotation joint. The sensor heads are fixed in position relative to the clevis end and the vane moves into the optic path of the relevant sensor as the joint is rotated into position. The two sensor heads are optically connected in series and a single set of optic fibres is connected back to the controller. In yet another alternative arrangement, the optic path is arranged along the tilt-rotation axis and the sensor head is fixed relative to the clevis end. The components are disposed such that the vane slots pass through the tilt-rotation axis at all positions of the tilt-rotation joint.

The inner arm casing is provided with a circumferential external drive track, coaxial with the tilt-rotation axis and located in the region external to the tilt-rotation bearing. When the arm is in the home position, the drive track bears against a drive wheel, orientated with its axis parallel to the tilt-rotation axis, and mounted in a substantially fixed position relative to the frame or housing of the apparatus. The apparatus is operable to rotate the drive wheel, and contact between the drive wheel and drive track causes the drive track and inner arm casing to rotate about the tilt-rotation axis. In the preferred arrangement, one of the contacting surfaces is provided with a durable rubber contact surface and the other surface is provided with a relatively hard surface, which may be ridged or roughened to increase frictional forces. In the preferred embodiment, the drive track comprises a rubber ring, with a substantially flat contact surface, located on a circumferential surface on the inner arm casing and the drive wheel is comprises of metal. The rubber ring is held in place by ridges, grooves or flanges on the rubber ring and/or circumferential surface. The rubber ring is arranged such that it may be easily replaced, for example by making it sufficiently resilient that it may be slightly stretched and

removed from the groove and passed over the arm and ball. Force is required between the contacting surfaces to provide sufficient traction to rotate the tilt-rotation joint. In a preferred arrangement, the drive wheel is positioned at a similar level to the drive track and is used in place of the stop which determines the home position of the arm. The horizontal-pivot returning means will maintain a force between the contacting surfaces. The drive wheel may be provided with a cushioned mounting to prevent damage being caused by the impact of the returning arm. In an alternative or additional arrangement, the vertical-pivot spring stop means is arranged such that it is operable to hold the arm at an angle slightly below the horizontal and the drive wheel is positioned under the drive track and lifts the arm slightly above the supporting position of the spring stop means when the arm returns to the home position. This will cause the weight of the ball and arm, magnified by leverage from the vertical-pivot, to be supported by the drive wheel. In this instance, the drive wheel must be capable of temporary downward movement when subjected to the significantly greater force caused by a ball being inadvertently struck downwards in a badly hit shot.

The tilt-rotation joint is arranged such that rotation is facilitated when the joint is rotated by the drive wheel but is inhibited when the arm is in motion in the drive shot. To this end, the tilt-rotation bearing is provided directly between the track and clevis piece to minimise the joint friction which arises from the force required to create contact traction between the drive wheel and drive track. The 180° movement of the joint is also arranged such that the arm shaft travels around the side of the tilt-rotation shaft which faces into the movement of the arm during the shot. This will cause the joint to attempt to rotate back against the stops when the arm is accelerated during the shot, due to the weight and inertia of the offset arm shaft. This arrangement also has the advantage that the region of the drive track which contacts the drive wheel, while rotation of the tilt-rotation joint takes place, is remote from the extended region of the inner arm casing which houses the vane and arm shaft, thus providing more space for the drive wheel arrangement. In the preferred embodiment, the contact surface of the drive wheel is wider than the contact surface of the drive track to allow for variation in the return position of the drive track following a shot.

The apparatus is also operable to rotate the tilt-rotation joint by a consistent 180°. This may be achieved in several ways. For example, the apparatus may be provided with sensing means and be operable to stop the rotation when the sensing means detects the completion of the 180° movement. Alternatively, the drive may attempt to rotate the joint by more than 180°, but be prevented from exceeding 180° by the stops which limit the rotation to that amount. Where necessary, in addition to the stops on the tilt-rotation joint, stops may also be provided at the home position of the apparatus which cause irregularities on the rotating inner arm casing to bear against corresponding irregularities which are fixed in relation to the apparatus, when the rotation reaches the relevant positions. In the preferred arrangement, the drive wheel is driven from a geared down output of a stepper motor which is controlled by the controller. The controller provides a set number of pulses to the stepper motor to ensure that the drive wheel just slightly exceeds the amount required for the 180° rotation. The excess rotation results in a small amount of forced slippage between the drive wheel and drive track. In an alternative arrangement, the drive to the drive wheel is provided with a slippage device, such as a spring loaded friction clutch, which allows slippage when the torque exceeds a predetermined value. In a further alternative arrangement, the drive is supplied by an electric motor which is operable to be stalled when the torque reaches a predetermined value and where the motor is not damaged by being stalled for the short duration of time that stalling occurs.

Use of the rotating-tilt embodiment may affect other aspects of the apparatus. The height of the apparatus may be reduced because the mechanism is no longer required to be raised and lowered. The length of the arm may require to be increased due to the increased size of the inner arm casing. The horizontal-pivot sensor vane may require to be modified or repositioned to avoid being fouled by the inner arm casing when the vertical-pivot rotates upwards to its maximum extent. This potential problem may be overcome, without increasing the height of the apparatus, in various ways including repositioning the vane on the underside of the horizontal-pivot, reducing the size of the vane on the side closest to the horizontal-pivot or increasing the distance between the vertical-pivot and horizontal-pivot.

Referring again to Figures 6 to 13, the arm and vertical-pivot are connected to the apparatus by a further pivot, henceforth referred to as the horizontal-pivot, which allows relative rotational movement in a horizontal plane between the arm and the apparatus. The horizontal-pivot allows the ball to move away from the club face by providing a horizontal component of movement. This provides another of the degrees of freedom necessary to allow the ball to follow its natural movement when struck. In the described embodiment, the horizontal-pivot comprises a horizontal-pivot block, a horizontal-pivot shaft and bushes within which the horizontal-pivot shaft rotates. The bushes are positioned on two stub arms of a further pivot, referred to as the supplemental-pivot. The shaft is composed of steel and the horizontal-pivot block is composed of polymer or reinforced composite polymer material. The shaft passes through a vertical hole in the horizontal-pivot block and is retained in position and prevented from rotating by a cross pin or grub screw.

The horizontal-pivot is provided with a sensing means which is operable to detect changes in the relative angle between the arm and the stub arms. The sensing means comprises a member with irregularities mounted on the horizontal-pivot shaft and a sensor head mounted on one of the stub arms. The sensor head detects the passing of the irregularities when the horizontal-pivot shaft rotates and communicates this to the controller. In the described embodiment, the member with irregularities comprises a disk shaped vane with radial open or closed slots around its circumference, similar to that used for the ball rotation sensing means. The vane is securely connected to the upper end of the horizontal-pivot shaft. The sensor head comprises a throated optical sensor head with an emitter lens and receiver lens transmitting a narrow light beam across the slot, again similar to that described for the ball rotation sensing means and operating in a similar manner. The controller monitors the resulting optical pulses over the period of ball movement following the impact between the ball and club head.

The horizontal-pivot is provided with a returning means, which is used to return the arm to the starting position after each shot. In the described embodiment, the returning means comprises a torsion spring mounted on the horizontal-pivot shaft, above the upper stub arm and below the vane of the sensing means. The lower extension end of the torsion spring is attached to the upper surface of the stub arm. The upper extension end of the torsion spring is attached to the

horizontal-pivot shaft. The torsion spring is partly wound, prior to final assembly of the parts, such that it urges the arm to rotate counter-clockwise against an arm stop. When a shot is taken, the arm rotates forward, in a clockwise direction, further energising the torsion spring. When the clockwise rotation of the arm stops, the torsion spring urges the arm back, counter-clockwise, until it comes to rest against the arm stop.

The arm stop positions the ball at a starting position which is set back from the perpendicular from the horizontal pivot to the line of intended flight of the ball, as can be seen in Figures 1 to 3. This set back distance is important in the measurement of the motion characteristics of the ball. It also has the advantage that the region where the ball is connected to the arm is kept away from the region where the club makes contact with the ball. In addition to keeping this weakened region of the ball away from the contact area, it also reduces the possibility of the club striking the arm where the shot is very badly directed. The set back position also advantageously causes the axis of the ball to be approximately perpendicular to the direction of movement during the period after the ball and club face lose contact with each other, immediately following the impact. This assists in promoting realistic ball flight during the period when its characteristics are being measured.

The apparatus is arranged in a manner which minimises the rotational inertia of the moving components of the apparatus about the horizontal-pivot. This is done for several reasons including the provision of a shot that feels and behaves similar to that with a free or unconnected ball. Another reason is to minimise the forces on the apparatus when the shot is taken, particularly at the region where the ball connects to the arm. Subject to a first overriding consideration of keeping the ball sufficiently distant from the apparatus such that its proximity does not disturb or influence the player's shot and a second overriding consideration of maintaining the various operation characteristics of the apparatus, the following guidelines should be followed. The distance between the ball and the horizontal-pivot should be minimised. The centre of gravity of the various components should be away from the ball and as close as possible to the pivot point. The weight of the components should be minimised.

The horizontal-pivot is connected to the apparatus by a further pivot, referred to as the supplemental-pivot, which allows a further degree of relative rotational movement in a horizontal plane between the horizontal-pivot and the apparatus. It allows the horizontal-pivot to move in a horizontal plane by rotation about a second vertical axis. This provides the third degree of freedom necessary to allow the ball to follow a substantially straight line movement, both when struck by the club and for a short period afterwards, when certain of the critical launch conditions are to be measured. In the described embodiment, the supplemental-pivot comprises a supplemental-pivot shaft with one upper and one lower stub arm and bushes within which the supplemental-pivot shaft rotates. The bushes are located on an outer support frame. The supplemental-pivot shaft and stub arms are composed of steel and the bushes are composed of polymer or reinforced composite polymer material. The stub arms are mutually parallel and are rigidly fixed to the supplemental-pivot shaft. They are provided with holes and bushes on their distal ends, within which the horizontal-pivot shaft rotates, as described earlier. The arrangement ensures that the horizontal-pivot shaft and supplemental-pivot shaft remain parallel to each other.

The supplemental-pivot is provided with a centering means which returns the supplemental-pivot shaft to a central home position after each shot. In the described embodiment, the centering means comprises two torsion springs and a rotational member. The rotational member and the torsion springs are mounted on the upper end of the supplemental-pivot shaft, with their centres or axes co-axial with the shaft.

One of the torsion springs, henceforth referred to as the stronger torsion spring, has one end connected to the support frame and the other end connected to the rotational member and is pre-wound such that it urges the rotational member to rotate counter-clockwise, until a stop on the rotational member, henceforth referred to as the frame stop, bears against a corresponding stop on the support frame. The other torsion spring, henceforth referred to as the weaker torsion spring, has one end connected to the support frame and the other end connected to the supplemental-pivot shaft and is pre-wound such that it urges the supplemental-pivot shaft to rotate clockwise, until a stop member on the shaft bears against a corresponding stop on the rotational member, henceforth referred to as the shaft stop. The springs are selected such that

the rotational moment of the stronger torsion spring is much greater than that of the weaker torsion spring. Accordingly, when the supplemental-pivot shaft is not subject to significant external rotational forces or moments, the stronger torsion spring drives the rotational member counter-clockwise to the point where the frame stop bears against the corresponding stop on the support frame. In this position, the weaker torsion spring drives the shaft to the rest position with its stop bearing against the shaft stop on the rotational member. When a significant external moment is applied to the shaft, such as would be caused by the motion of a driven ball acting on the arm, the shaft may rotate clockwise or counter-clockwise. The springs are also selected such that the spring forces are very much less than the external forces arising from motion of the ball and accordingly do not significantly affect the motion of the ball. If the shaft rotates clockwise from the rest position, the stronger torsion spring is wound tighter and the rotational member will follow the movement partly unwinding the weaker torsion spring. If the shaft rotates counter-clockwise from the rest position, the weaker torsion spring is wound tighter, but the stronger torsion spring and the rotational member remain at the rest position. The supplemental-pivot is provided with a stop which limits its ultimate rotation in a counter-clockwise direction. The supplemental-pivot will rotate to this stop and away from it again over the course of all normal shots.

Within the constraints of the design requirements, the joints and interconnecting members are arranged such that the components of the apparatus, where possible, are subjected to tension rather than bending stresses when they resist the substantial forces required to restrain the ball, the components thus being stronger and less liable to failure or distortion. Where the rotational movement of the joints is limited by stops, these stops are cushioned or sprung to prevent shock stresses occurring by abrupt redirection of the ball movement.

The supplemental-pivot is provided with a sensing means which is operable to detect changes in the relative angle between the supplemental-pivot shaft and the support frame of the apparatus. The sensing means comprises a member with irregularities mounted on the supplemental-pivot shaft and a sensor head mounted on the outer support frame. The sensor head detects the passing of the irregularities when the supplemental-pivot shaft rotates and communicates this to the controller.

In an embodiment which is shown in the figures, the supplemental-pivot sensing means is operable to detect the magnitude and direction of rotation of the supplemental-pivot. The member with irregularities comprises an arm vane with a central region along its circumference without slots. It also comprises two regions with slots on the two adjacent regions of its circumference. Two sensor heads are provided, comprising optical throated sensor heads, each with an emitter lens and receiver lens transmitting a narrow light beam across the slot. The sensing means are similar, operate similarly and have similar advantages to those described for the previously mentioned sensing means. The light beams are communicated between the controller and the sensor heads by means of flexible optical fibres, which are supported by means attached to the outer support frame. The sensor heads are located in relation to the vane such that when the supplemental-pivot is in the rest position, one of the sensor heads reads the first slot position adjacent the central region without slots and the other sensing head reads the first slot position adjacent the other side of the central region without slots. When the supplemental-shaft is in the rest position, ON signals are received from both sensors. If the shaft rotates clockwise, one of the sensor heads will produce a series of ON and OFF signals as the sensing head traverses the slots in the vane. The other sensing head will continuously read OFF since it will be traversing the region of the vane without slots. If the shaft rotates counter-clockwise from the rest position, the signal pattern will be reversed in the two sensor heads.

In a preferred embodiment, the sensing means comprises a single sensor head and the vane comprises only two slots. This embodiment is not shown in the figures, but is similar to the type which is shown. Again, the sensing means comprises a light optical sensor which is the same or similar to that described for the ball-rotation sensing means and the horizontal-pivot sensing means. However, in this instance the member with irregularities comprises an arm vane with just two slots, each of which passes through the locus of the sensor head. One slot corresponds to the central home position of the supplemental-pivot and the other corresponds to its furthest clock-wise position where rotation is limited by the stop. The sensor head is mounted on the support frame and the arm vane is securely connected to the supplemental-pivot shaft.

The apparatus is arranged in a manner which minimises the rotational inertia of the moving components of the apparatus about the supplemental-pivot, for reasons similar to those related to minimising the rotational inertia about the horizontal-pivot.

The supplemental-pivot is connected to a supporting frame which supports the supplemental-pivot, including the bushes in which the supplemental-pivot shaft rotates. The supporting frame is operable to be vertically raised or lowered by a lifting or actuator means. The figures show an embodiment of the supporting frame which uses a pivoting movement. In this embodiment, the supporting frame comprises an outer supporting frame, an inner supporting frame, four frame shafts and four frame arms. The outer supporting frame is provided with holes to receive bushes within which the vertical supplemental-pivot shaft is operable to rotate. It is also provided with four holes and bushes within which two of the horizontal frame shafts are operable to rotate. The inner supporting frame is also provided with four holes and bushes within which the two other horizontal frame shafts are operable to rotate. Two of the frame arms are rigidly connected to one of the frame shafts on the inner support frame. These frame arms are parallel to each other and at right angles to the frame shaft. The other two frame arms are similarly connected to the other frame shaft on the inner support frame. Each frame arm is provided with a hole and bush at its distal end at an equal distance from the frame shaft. The two shafts on the outer frame run through these bushes such that the outer and inner frames are linked by the arms. By simultaneous rotation of the shafts and arms, the outer support frame is operable to move up or down relative to the inner supporting frame without variation to its orientation such that the supplemental-pivot remains vertical throughout the movement. The supporting frame is arranged such that the arms are inclined by the same angle above the horizontal in the raised position, as they are inclined below the horizontal in the lowered position. This advantageously causes the outer supporting frame to be in the same position in the horizontal plane for both the raised and lowered positions. The supporting frame is raised or lowered by the application of a turning moment to one of the shafts on the outer frame. In an alternative embodiment of the supporting frame, the supporting frame is provided with a vertical sliding means, which permits vertical movement of the supporting frame. The lifting or actuator means may comprise a screw means, comprising a lead screw and threaded bush, one of which is connected to the moving

part and the other to the stationary part of the frame. Relative rotation of the lead screw and threaded bush causes a controlled movement of the lifting or actuator means.

In an electrically actuated embodiment of the apparatus, which is not shown in the figures, the supporting frame is operable to be vertically raised or lowered by an actuator means which comprises an electrically powered actuator such as a screw means and a linear actuator or stepper motor. The linear actuator or stepper motor may be driven by electrical pulses from the controller. The reciprocating movement of the electric actuator is set at a reference point by a sensing means which is operable to detect when the moving parts are at a reference position. The sensing means may comprise, for example, an electrical proximity switch or an optical sensor similar to that described earlier.

The ball and arm are retarded after a partial rotation of the horizontal-pivot and supplemental-pivot by a ball retarding means where the ball or arm strikes an energy absorbing means, which in its simplest form may comprise a flexible receptacle of energy absorbing material such as gel or sand. However, in a preferred embodiment, energy is recovered when the ball and arm are retarded and used to power the movement of the apparatus to achieve the variation in the angle of the axis of rotation of the ball. To achieve this end, the ball retarding means is operable to obstruct the path of the ball and gradually decelerate it to a stopped position. In the described embodiment, the ball retarding means comprises a contact pad and a pivoted retarding arm. The contact pad is connected to the distal end of the retardation arm. The retardation arm is operable to rotate about a vertical pivot axis, which is sufficiently close to the horizontal-pivot axis such that the contact pad obstructs the path of the ball over the movement range of the retarding arm. The retarding means rotates between a home position and an end position when the ball is in contact with the contact pad. A return spring and stop causes the retarding arm to return counter-clockwise to the home position. The retarding means is provided with spring and damping means and is operable to absorb the kinetic energy of the ball and arm. The contact pad is made from a soft durable material such as rubber.

In one embodiment of the invention, kinetic energy is recovered from the retardation means and converted into electrical energy. One example of this embodiment, a flywheel is connected to

the retarding means by a ratchet means which drives the flywheel when the retarding means returns to its home position under the influence of the retardation means return spring. The connection may include a gearing means to increase the rotational speed of the flywheel. However, the ratchet means does not drive the flywheel when the retarding means moves in a clockwise direction in its outward movement following the shot, when the retardation means spring is being energised. The resulting rotation of the flywheel is used to drive an electrical generating means such as a dynamo, which converts mechanical to electrical energy. In one embodiment of the invention, the electrical energy is used to directly drive the movement of the axis tilt device, with the movement being completed before the flywheel comes to rest. In an alternative embodiment, the electrical energy is stored in a rechargeable battery and used as required.

In an alternative embodiment, the axis tilt device is mechanically powered from the energy recovered from the ball by the retardation means. A collecting means collects part of the retardation energy, which is stored by a storage means. Storage is necessary because retardation occurs too rapidly for the energy to be instantaneously used to move the axis tilt device. A regulating means is used to release energy from the storage means at a regulated rate. A transmission means is used to transmit this energy to the axis tilt device and a switching means is used to cause the tilt to be switched between the required tilt angles. The collecting means either collects energy during retardation of the ball or when the retardation means is returning to its home position. It may comprise a pivoting retardation arm, as shown in the Figure 11, or it may comprise a linear retardation means. The storage means may comprise a flywheel or a spring. For example, where a flywheel is used, it may be driven by a ratchet arrangement, which drives the flywheel in one direction and allows free rotation in the other direction. As a further example, where a spring is used, the spring may be fitted within a bellows, and the ball may impact against a linear retardation means which compresses the bellows and spring, and simultaneously exhausts air from the bellows through a check valve. An additional example of the use of a spring, is where the same spring is used to return the ball to the home position and to power the axis tilt device. The regulating means may comprise a geared arrangement such as a worm and pinion, which is operable to draw energy from a flywheel at a regulated rate. In another example, the regulating means may comprise a rotating fan which is operable to attain a

limiting rotational speed. As a further example, the regulating means may comprise an air flow restriction, such as an air restriction orifice on the entry of air to a bellows which is urged to extend by a spring. The transmission means may comprise a rotating linkage or sheathed cable, which drives a lead screw and threaded bush. As another example, the transmission means may comprise a pull or release linkage or sheathed cable, which activates the axis tilt device by back or forth movement. In a further example, the transmission means may comprise one or more tubes through which air moves, either under suction or compression, and which are operable to actuate bellows or pistons. The switching means may comprise a geared device which is operable to switch the direction of rotation when activated on each cycle related to shot occurrence. As another example, the switching means may comprise a mechanical device which is operable to alternately latch and release on each cycle related to shot occurrence. These cycles may correspond, for example, to the cycles of the retardation means or the cycles of a transmission means such as a reciprocating lead screw arrangement. In a further example, the switching means may comprise a solenoid air valve which is controlled by the controller.

The apparatus is mounted in a protective housing. The housing has a front opening through which the ball and arm protrude and which allows movement of the arm and ball. The electronic components, including the controller and display screen, are mounted within the housing or above the housing in a sealed controller enclosure. The components may be additionally protected from damage arising from shock when the ball is struck by means such as the use of shock or vibration isolating mountings. The housing is also provided with a protective club buffer to prevent damage to the apparatus or the club, or injury to the player, in the event of the club inadvertently striking the housing. The club buffer may comprise a resilient rubber moulding fixed to the side of the housing. The apparatus is also provided with a protective ball buffer to prevent direct rebound or damage to the upper edge of the housing front opening in the event of a ball being inadvertently lofted at an unusually high angle. The ball buffer may comprise a resilient rubber moulding fixed to the upper edge of the housing. The ball buffer may comprise an angled deflecting surface which will deflect a contacting ball in a downward direction.

A tee mat, with a durable simulated tee surface, is provided under the region of the ball.

The tee mat is provided with one or more lines or patterns to indicate the direction of a straight shot to the player. The player stands on a second mat to elevate his or her ground height to a height equal to or just below that of the surface of the tee mat. The tee mat, housing and arm are arranged to be visually unobtrusive. Ideally, they are provided in a contrasting colour to the ball, such as dark green, dark grey or black. The apparatus is also provided with a tee height adjustment means, which is not shown in the figures. This may, for example, comprise a means to raise or lower the mechanism and upper part of the housing relative to the level of the ground.

The apparatus is arranged with a minimum overall height in order to reduce the necessary height of the player mat and to reduce the visual obtrusiveness of the housing. In practice, its height is less than that shown in the figures, which show a magnified representation of certain of the dimensions for the sake of visual clarity. For example, the overall height can be significantly reduced without reducing the strength or rigidity of the horizontal-pivot or supplemental-pivot, by rearranging the components such that the relevant springs, rotational member and sensors are mounted at levels between the stub arms and arms of the outer supporting frame. The apparatus may also be selectively arranged such that the nominal ball position is raised or lowered in relation to the other parts of the apparatus to suit particular requirements. For example, the necessary player mat height may be reduced by accepting an increase in the height of the housing relative to the ball. Alternately, the height of the housing relative to the ball may be reduced where a relatively high player platform or mat is used. These variations may be effected by conventional design variations or by using unequal arm tilt angles for the tilted up and tilted down positions. For example, where the lifting-tilt embodiment is used, a very low mat height can be achieved by arranging the arm to be horizontal when the mechanism is lowered and at a relatively steep angle down to the ball when the mechanism is raised. Where the rotating-tilt embodiment is used, unequal arm tilt angles can be utilised by arranging the ball centre to be above or below the tilt-rotation axis.

The controller is connected to a display screen, a player selector means and an external output port.

The display screen is directed towards the player to allow it to be readily viewed without the need for the player to vary stance between successive practice shots. This is advantageous for the player in isolating and correcting faults or improving specific aspects of play. The apparatus is operable, following each shot, to display values on the screen for initial ball speed, direction, loft angle, back spin and side spin. It is also operable to indicate the distance the shot would have travelled, if it had been a free or unconnected ball on an open course, and the deviation to the right or left of centre which it would have taken. In addition, it is operable to indicate the proportion of the deviation which is due to incorrect direction and the proportion which is due to hook or slice. Further trajectory details, such as roll-on, may be included, if required. The controller and screen are operable to display these values in various ways. For example, they may be displayed as simple values for the last shot played or they may be displayed in a statistical manner related to previous shots, details of which are memorised by the controller. The player selector means may comprise a keypad which operates in conjunction with instructions and choices displayed on the screen. The player selector means is used by the player to select various options including the required type of display or settings which simulate different types of playing conditions.

An external output, such as an output port, is provided to allow the apparatus to be optionally connected to peripheral processing and display equipment, such as computers, computer screens and digital projectors. The external output communicates the relevant signals from the apparatus and can be provided with little additional cost. When appropriately programmed, the peripheral equipment may, for example, project a simulated three dimensional representation of the shot on a relatively large screen or display it on a computer monitor. The external output may also used to communicate details of the shot to equipment programmed to assist player instruction, either as an aid to an instructor working with a player or as an interactive aid used by the player without the need for the presence of an instructor. The external output may additionally be used to assist fitting and selection of golfing equipment or to provide an input to golf simulation gaming equipment.

The rotation and retardation of the moving parts of the apparatus may cause it to move relative to its ground position. This movement can be prevented by the employment of restraining

means. The restraining means may comprise pins or fasteners which fix the apparatus to the ground. For example, pins or stakes fitted through lugs on the side of the casing may be used to fix the apparatus to a surface such as grass or soil. Alternatively, the restraining means may comprise a weighted component or the application of weighted components. For example, the apparatus may be attached to a receptacle which may be filled with water or sand. In a further example, the apparatus may be attached to members which lie on the ground and upon which readily obtainable heavy objects may be placed. As a further alternative, the restraining means may comprise the player mat and the weight of the player. For example, the apparatus may be provided with a frame which is connected to the casing and the player mat.

The apparatus is provided with a small free standing safety net to protect against the unlikely event of the ball or other parts breaking away from the apparatus during a shot. The safety net is of much lighter construction than a typical golf practice net because it is permissible for the safety net to travel a small distance when restraining moving parts and also because it does not require to be operable for frequent use. The safety net is also much smaller than a practice net because it can be positioned closer to the apparatus than a practice net, which requires the player to observe the flight of the ball into the net.

The following dimensions are proposed for use with the apparatus described in the lifting-tilt embodiment of the invention. The ball has a diameter of 42 mm. Its centre is 150 mm distant from the centre of the horizontal-pivot axis. The ball centre is also set back about 30 mm behind the perpendicular from the intended line of flight to the horizontal-pivot axis. This corresponds to an angle of about 11.5° between the arm and the stub arm. The diameter of the arm shaft is between 5 mm and 8 mm at the critical section adjacent the connection to the ball. The diameter is about 5 mm on the section of the arm shaft between the critical section and the threaded joint. The centre of the horizontal-pivot axis is about 9 mm distant from the centre of the vertical-pivot axis and about 40 mm distant from the centre of the supplemental-pivot axis. The angle of rotation of the horizontal-pivot is limited to about 200° from the home starting position and is prevented from making any reverse rotation from the home position by a stop which bears against the arm casing. The rotation of the supplemental pivot is limited to about 22.5° to 23.0°

counter-clockwise from the central home position, but is not limited in a clockwise direction, over the range of movement before the ball is stopped by the retardation means. This allows the direction of shots to be measured where they vary up to ±15° from a straight line shot. The angle of rotation of the vertical-pivot is limited to about 30° above and about 20° below the horizontal. The tilt positions of the shaft are arranged such that the shaft tilts down 6° towards the ball when the horizontal-pivot and supplemental-pivot assembly is raised, and tilts up 6° towards the ball when it is lowered. The travel distance of the actuator and assembly is about 30 mm. On all sensor vanes, the open slot gap width and interstitial width between gaps are each arranged at about 1 mm, that is about 2 mm per complete slot, where measured along the locus of the optic beam on the vane. The slots are of the closed type to provide additional strength and to prevent snagging of the edges. For purposes of clarity, slots are shown open and on an exaggerated scale in the figures. The radius of the locus of the optic beam is about 11.5 mm, 23 mm and 57 mm on the ball-rotation, horizontal-pivot and supplemental-pivot sensor vanes, respectively. The ball rotation and horizontal-pivot vanes are slotted around their full circumferences and comprise 36 and 72 complete slots, respectively. Alternatively, the portion of the horizontal-pivot vane, which does not pass through the sensor, may be provided without slots. The supplemental-pivot vane does not comprise a complete disk and is provided with just two slots, one corresponding to the home position and one corresponding to the extreme counter-clockwise position, approximately 22.5° to 23.0° from the home position.

The same dimensions are proposed for use with the apparatus described in the rotating-tilt embodiment of the invention, with the exception of the dimensions indicated below. The ball centre is 180 mm distant from the centre of the horizontal-pivot axis. The ball centre is set back about 36 mm behind the perpendicular from the intended line of flight to the horizontal-pivot axis. This also corresponds to an angle of about 11.5° between the arm and the stub arm. The centre of the horizontal-pivot axis is about 10.5 mm distant from the centre of the vertical-pivot axis. The two tilt positions of the shaft are 10° up or down towards the ball. The ball-rotation sensor vane has an optic beam radius of about 14.0 mm and comprises 44 complete slots.

OPERATION OF AN EMBODIMENT OF THE INVENTION.

The following describes an example of a method of operation of the preferred tilt-rotation embodiment of the invention. The apparatus automatically sets itself at its home or rest position prior to the commencement of each shot. The arm bears against the arm stop, positioning the ball at a set distance of about 36 mm behind the perpendicular from the intended direction of travel to the horizontal-pivot centre. The supplemental-pivot shaft is at the central home position.

When the apparatus is switched on by the player, the horizontal-pivot and supplemental-pivot sensors return ON signals in the home and central positions, respectively. The controller communicates any deviation from this normal starting condition. The ball rotation sensor does not have a home position and may return an ON or OFF signal at the commencement of the shot. The controller checks the memorised previous position of the tilt axis. If the information is lost or the axis is memorised as being tilted up towards the ball, the controller rotates the tilt-rotation joint to move the axis to the position where it is tilted 6° down towards the ball. If the axis is memorised as being tilted down towards the ball, the controller rotates the axis by a small amount to ensure that it is fully in position.

The player may vary the tee height of the ball by mechanical adjustment of an adjustment means which varies the height of the base beneath the apparatus. One or more parallel lines or patterns, marked on the mat beneath the ball, advise the player of the intended direction of ball travel. The player then takes a shot driving the ball from the starting tee position.

For a typical well hit shot, the club face remains in contact with the ball for about 0.45 ms, over which time it drives the ball forward by about 15-20 mm. The ball will substantially move in a straight line over this period and will depart from the club face in a substantially continued straight line motion, with a speed of about 65 m/s. At this early part of the ball's flight, the arm is free to move in three dimensional space and the restraining forces of the return and centering springs are insignificant compared to the force of the impact from the club face and the forces

resisting change to the momentum of the ball travelling at its launch speed. Accordingly, the ball will move in a linear direction, which is substantially identical to that which it would take if it were not connected to the arm. Where the device is constructed in accordance with the dimensions of the described embodiment, this linear flight will continue for about 118 mm for a straight shot, and ranging from about 71 mm to 180 mm for extreme shots at 15° to the left and 15° to the right, respectively. For the next part of its flight, as projected on a horizontal plane, the ball will move through a circular arc of radius 180 mm about the horizontal-pivot until such time that the arm is aligned with a line passing through the horizontal-pivot and supplemental-pivot, after which the ball will move through a circular arc of 220 mm about the supplemental pivot, until the ball is finally stopped by the retardation means. These flight paths are shown in Figures 1 to 3. If the ball travels the first 18 mm in contact with the club face over a time duration of 0.45 ms and then travels freely at 65 m/s in substantially free flight, then the distance and time period from when it leaves the clubface to when it is ends its free flight ball will be approximately 63 mm (71-18) and 0.969 ms for a shot which is 15° to the left; 100 mm (118-18) and 1.538 ms for a straight shot, and 162 mm (180-18) and 2.769 ms for a shot which is15° to the right.

In the described embodiment, the supplemental-pivot is provided with just one sensor and the sensor vane is provided with just two slots, one slot corresponding to the central home position and the other slot corresponding to the extreme measurable counter-clockwise position. The horizontal-pivot sensor vane is provided with the maximum number of slots along its operating region. The controller monitors the status of the horizontal-pivot sensor and the supplemental-pivot sensor during the flight of the ball, recording the times when all signals are detected. The angle of direction of flight and the speed of flight are computed over the period when the ball has departed from the club face and straight line flight takes place. This has several advantages. The measurements are little affected by the elevation of the arm. The measurements are carried out before possible distortion arises from the shock or strain when the ball is pulled into circular orbit. The computations are more acceptable to the player because the measurements are known to be taken with the ball is in realistic straight line flight. –

The direction of flight of the ball can be determined by measurement of the angles at the horizontal-pivot and supplemental-pivot because the connection means is in a unique arrangement for each possible position of the ball, within the limits of such movement. The measurement can be made in numerous ways, and the following is given as one example. The supplemental-pivot commences movement either clockwise or counter-clockwise, depending on whether the shot is to the right or left. However, as straight line movement progresses, the supplemental-pivot ultimately moves to the extreme of the measurable counterclockwise positions whereupon the controller measures the angle at the horizontal-pivot. The angle of the horizontal-pivot at this point is unique for each angle of direction of the shot, and the latter can be readily computed, either by trigonometric calculation or from a set of pre-calculated values matching directional angle against horizontal-pivot angle. The measurement points and measurement angles are shown as L and AKL, respectively, in Figures 1 to 3. A straight shot is indicated, if the supplemental-pivot angle is at the zero position when the horizontal-pivot has described an angle which is twice the angle at which the ball was set behind the perpendicular from the intended direction of travel to the horizontal-pivot centre at the home or starting position. The controller checks for this condition during the course of each shot. The check position and angle are shown as J and ABJ, respectively, in Figure 1.

In the various measurements described above, the supplemental-pivot angle is read at specific points, usually the commencement of a signal, and the measurement is not subject to any resolution error. Measurement of the horizontal-pivot angle, however, is recorded as a series of discrete pulses, which provides a relatively coarse resolution, since the final portion of angle which corresponds to less than one slot spacing, is not read by the horizontal-pivot sensor. In the described embodiment, this resolution is 5° where the signal is registered at an identical point on each signal. This potential problem is overcome by arranging the controller such that it measures and records the time duration between pulses from the horizontal-pivot sensor and measures the time duration of the final part pulse, which is terminated by the signal from the supplemental-pivot sensor. The angle corresponding to this final part pulse is calculated by comparing its duration to the time duration of the previous full pulses. For example, if the final counter-clockwise position on the supplemental-pivot was detected 0.18 ms after the final

detected slot on the horizontal-pivot, and if the time duration between the final detected slot and the previous slot on the horizontal-pivot was 0.42 ms, then if a constant rate of change of angle is assumed, the controller would estimate that the zero position was detected at [0.18/(0.18+0.44)] x 5° = 1.45° after the 5° position, i.e. at 6.45°. If required, the calculation may also take account of the time duration of earlier intervals between slots to make allowance for changes in the rate of change of the angle or may make mathematical allowance for the geometry of the arm and stub arm. Inspection of Figures 1 - 3 shows that the starting angle ABC of the horizontal-pivot is about 78°, and that this increases to about 122°, 140° and 164° for 15° left shots, straight shots and 15° right shots, respectively, shown as angle AKL in the figures. These increases in angles correspond to 8, 12 and 17 complete slot signals for 15° left shots, straight shots and 15° right shots, respectively.

The ball speed is also calculated from the data collected during the period of straight line flight. This can be achieved in several ways. For example, it may be directly calculated by trigonometric calculation by the controller from the recorded angles and times at the horizontal-pivot and supplemental-pivot sensors, deleting the initial period when the ball is accelerated during impact with the club face. In another example, it may be calculated by timing the duration from a starting point in the detection of movement of the ball by the horizontal-pivot sensor to the point where the supplemental pivot sensor detects that the ball has completed straight line movement and is about to be pulled into circular orbit. The controller may them apply an empirical calculation to convert this to an appropriate ball velocity, having first determined the angle of direction of the shot. The starting point in the detection of movement of the ball may be arranged such that it occurs after the initial period where the club face is in contact with the ball, for example commencing not less than 7° of movement by the horizontal pivot, or from the two full slot intervals where slots are evenly arranged at 5° intervals. The ball speed may also be calculated while the ball is in circular orbit about the horizontal-pivot and/or the supplemental-pivot, by timing the time duration between angular points on this flight. Where the supplemental-pivot sensor is used to register the end of the timed orbit, an additional slot is provided at an appropriate position in the sensor vane.

The player's perception of feel for the shot will be similar to that for a conventional unconnected shot because the inertia of the apparatus is arranged to be substantially similar or identical to that of an unconnected ball. Visual feedback plays a relatively minor part in the golf drive shot because the typical human reaction time for this sense is about 20 ms to 100 ms, depending on how it is measured. A ball travelling at 65 m/s will therefore travel between 1.3 m and 6.5 m in this short time interval. Furthermore, since it is regarded as poor practice for the player to look immediately after the ball which he has struck, the player does not normally see the ball at all until it has travelled far down the fairway.

The controller also determines the speed of rotation of the ball about its own axis in the time period between the ball departing the club face and making contact with the buffer pad on the retardation means. This is achieved by timing the duration between the first signal obtained from the ball rotation sensor, after the horizontal-pivot sensor has indicated that the ball has departed the club face, and the signal before the horizontal-pivot sensor has indicated that the ball has moved into the region of the buffer pad. Where the horizontal-pivot vane is arranged at 5° per slot, the measurement may, for example, commence after the third slot signal and terminate before the twentieth slot signal. Both signals should relate to the same point on the signal cycle, such as the start of the signal or the end of the signal. The rotational speed is readily determined from knowledge of the number of signals received, the time duration between the first and last signals and the number of slots on the ball rotation sensor vane. For example, if the vane has 44 slots and the controller records a time duration of 5.011 ms over 13 signals, then the rotational speed is indicated to be (13 x 1000) / (44 x 5.011) = 58.961 revolutions per second.

The ball will continue its orbit until it is brought to a stop by the retardation arm. The arm return spring then returns the arm and ball to the starting tee position. When the shot is complete, the apparatus reverses the tilt of the arm. The controller may apply various criteria to judging the completion of the shot to ensure that small movements of the ball or very weak hits are not registered. For example, the criteria may be a specific number of pulses from the horizontal-pivot sensor within a specified time, where these relate to a full movement of the arm from the

stop to the buffer and where the speed is greater than the minimum speed expected for a drive shot.

Reversal of the tilt is achieved by the apparatus reversing the tilt-rotation joint until the joint bears against the stops in the position where the arm tilts up to the ball. The controller controls this movement by generating a set number of pulses to the stepper motor in reverse motion format. The set number of pulses is sufficient to cause 180° of rotation plus a small excess amount where the drive wheel skids against the drive track. The ball height at the end of this movement is the same as before the movement. The shaft and ball axis are then tilted at an angle of 10° downwards from the ball. A second shot may then be taken by the player and new values for ball speed, ball flight angle and ball spin are obtained. The controller determines the components of back spin and side spin by comparing the spin value to that obtained on the previous shot.

The principle is illustrated by the following typical example where a spin rate of 52.2072 revolutions per second is detected on the first shot, with the axis tilted down 10° towards the ball, and a spin rate of 54.9398 revolutions per second is detected on the second shot, with the axis is tilted up 10° towards the ball. The magnitude of the spin rate S and inclination to the horizontal ϕ which would occur if the shot was free to spin about its natural axis not constrained by the arm, is calculated from the relationships $S_1 = S.\cos(\phi + \beta)$ and $S_2 = S.\cos(\phi - \beta)$. Therefore, $52.2072 = S.\cos(\phi + 10)$ and $54.9398 = S.\cos(\phi - 10)$. Solving for S and ϕ gives $S = 54.401$ and $\phi = 8.23°$. The component of back spin and side spin can now be calculated. Back spin is equal to $S.\cos\phi = 54.966$ revolutions per second. Side spin is equal to $S.\sin\phi = 7.808$ revolutions per second. Since the spin rate is greater when the axis is tilted up towards the ball, the ball flight will veer towards the right, resulting in a shot which is a slice or fade.

When a third shot is taken, the device reverses the tilt of the arm again by rotating the tilt-rotation joint back to its original position. With successive shots, the tilt is alternated between the two tilt angles. The apparatus may display results derived from comparing single or averaged measurements taken at each of the two tilt angles, or may display both, as required.

The apparatus is also operable to determine the uniformity with which shots are taken and to apply this to determine the reliability of the spin characteristics, because the method relies on successive shots being substantially similar. For example if the spin characteristics of a third or further shot is the same or similar to earlier shots where the axis was tilted in the same direction, this will imply that shots are being taken uniformly and that the indicated spin characteristics are reliable. Conversely, if quite different spin characteristics are measured for shots taken with the axis tilted in the same direction, this will indicate an inadequate uniformity in the player's swing for reliable analysis to be made of the components of spin. The apparatus may signal this uncertainty to the player and request further shots until a sufficient level of uniformity has been produced and recorded. The identification of such inconsistency provides an additional useful basis for player instruction.

With minor modification, the method and apparatus of the invention may be used to measure the motion characteristics of other golf shots where the ball is hit off the ground rather than off a tee. Such shots are similar to drive shots, except that the range of loft angles is greater and the ball speed and energy is usually much lower. A resilient and durable mat, with a relatively deep pile may be used below the suspended starting position of the ball. The loft angle or vertical pivot angle may be measured by an appropriate sensor. Variations of the apparatus may also be used to measure the motion characteristics of shots in other sports where a ball is struck by an object or implement.

MACLACHLAN & DONALDSON,
Applicants' Agents,
47 Merrion Square,
Dublin 2.

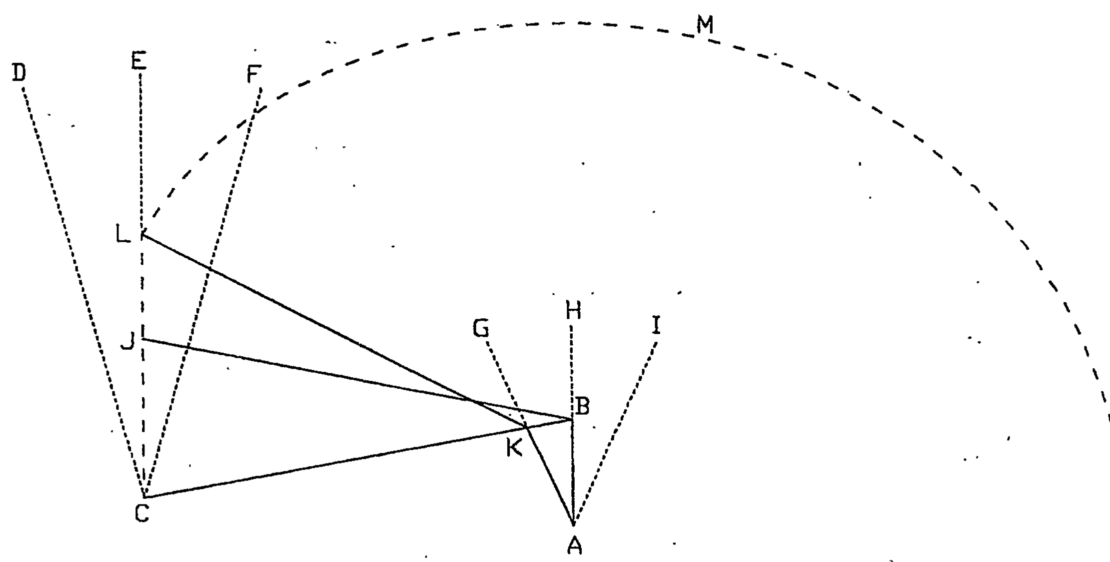

FIGURE 1

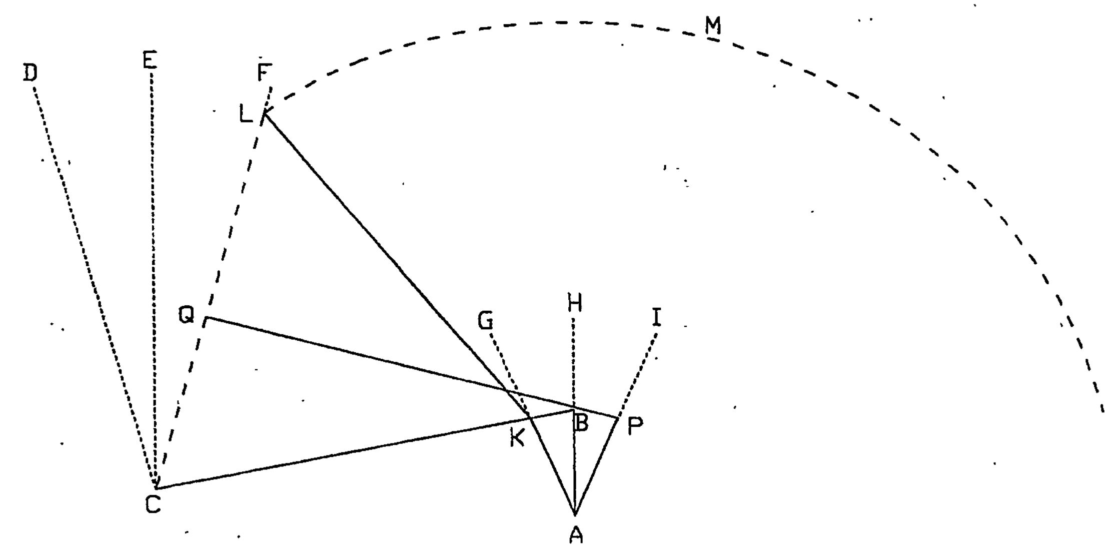

FIGURE 2

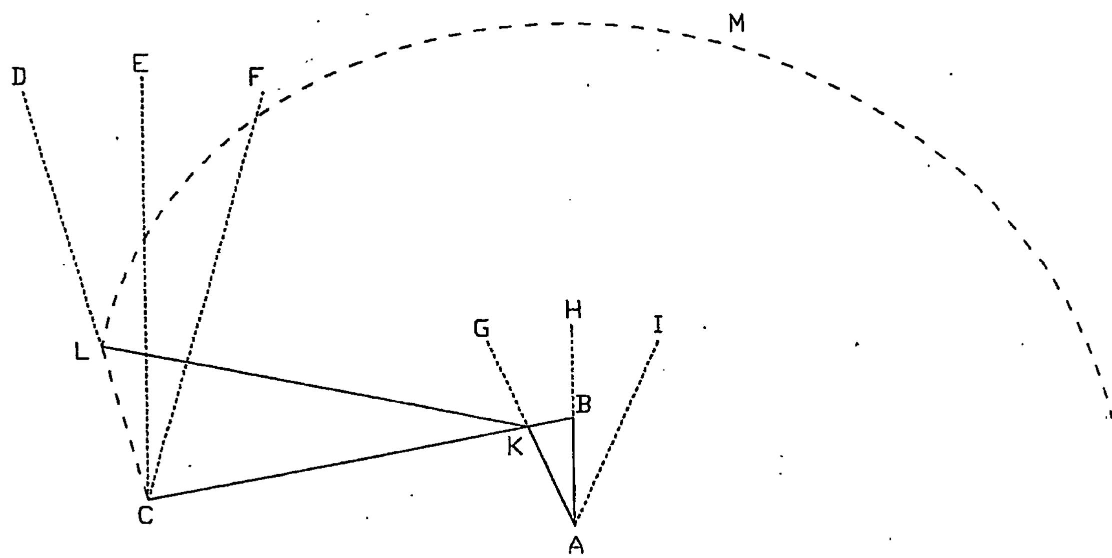

FIGURE 3

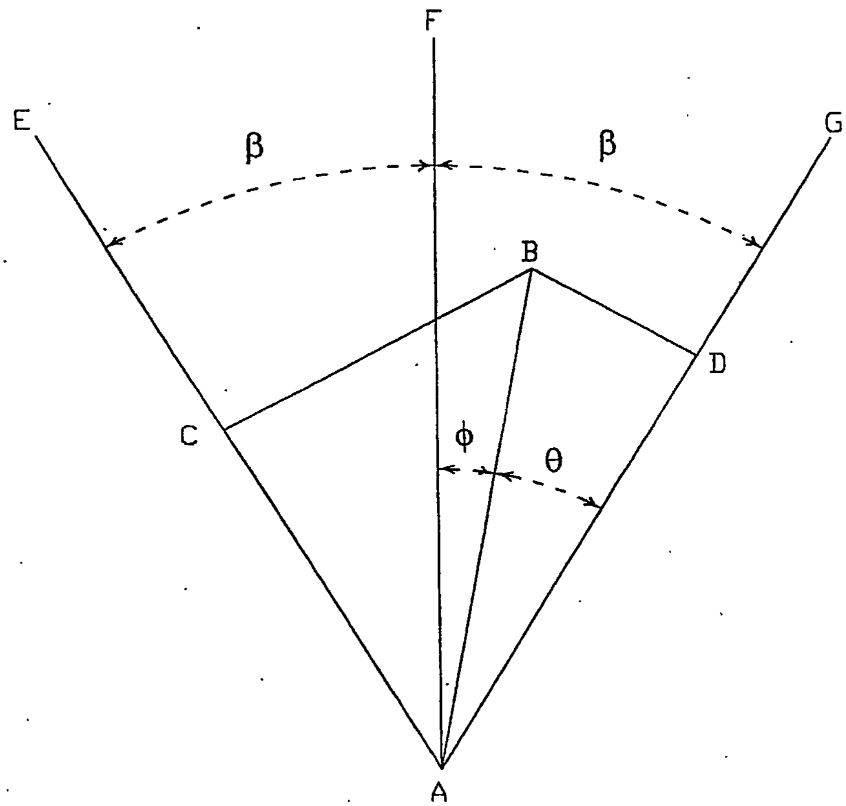

FIGURE 4

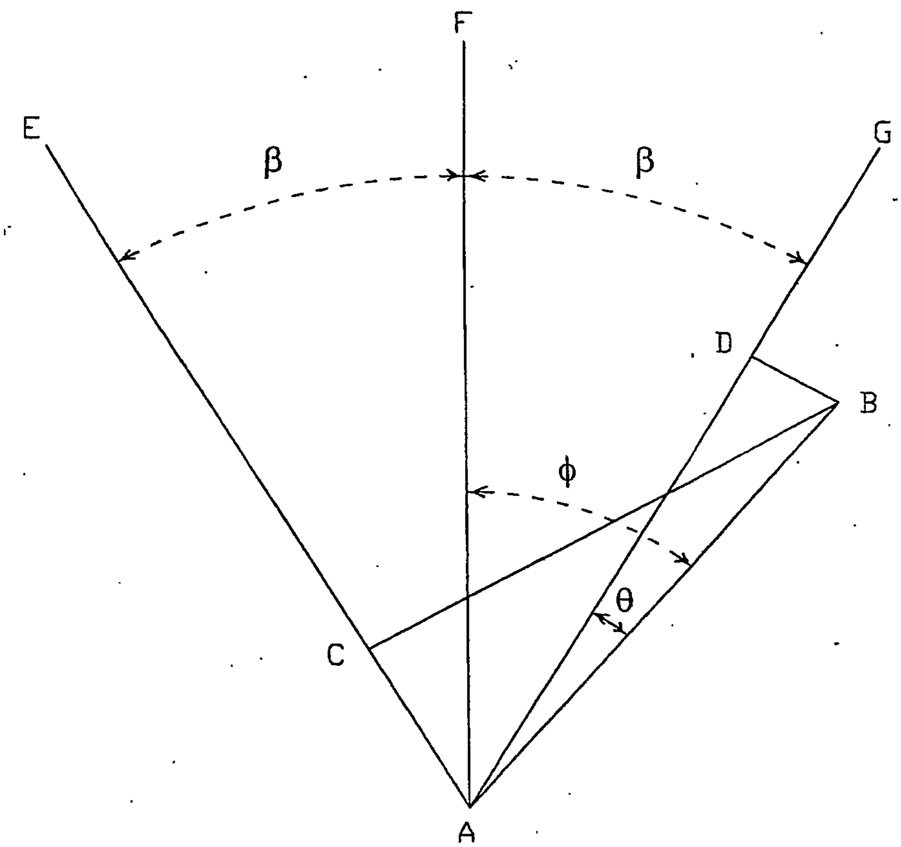

FIGURE 5

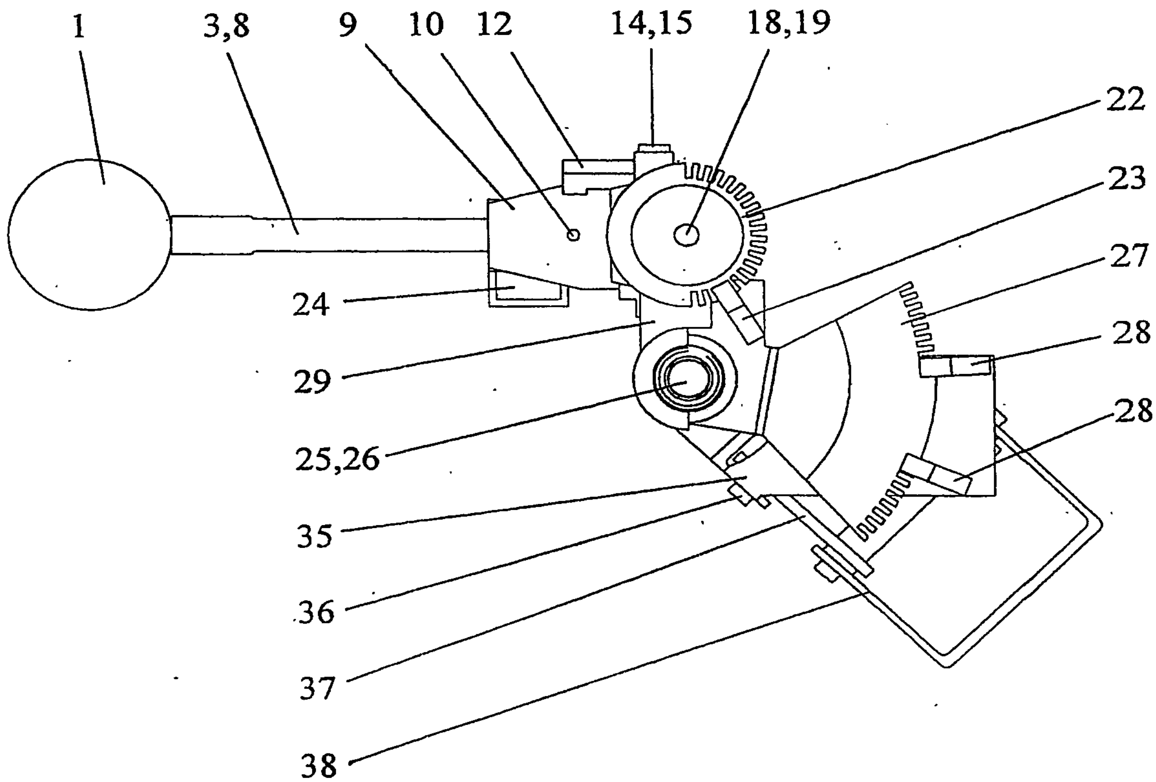

FIGURE 6

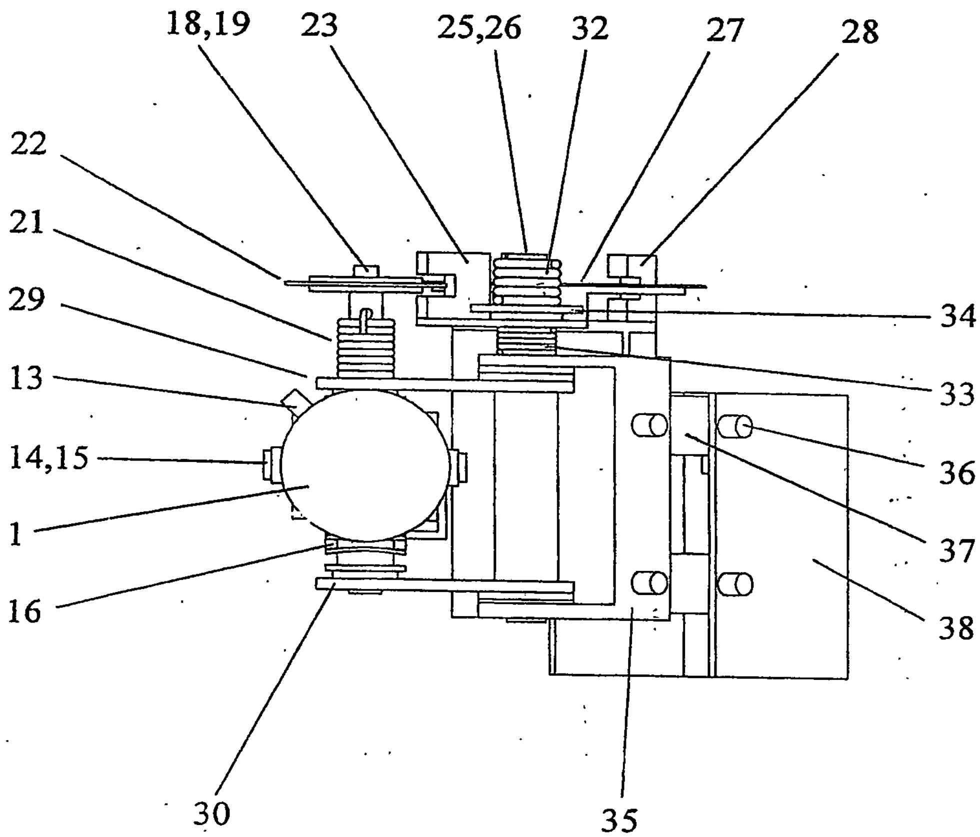

FIGURE 7

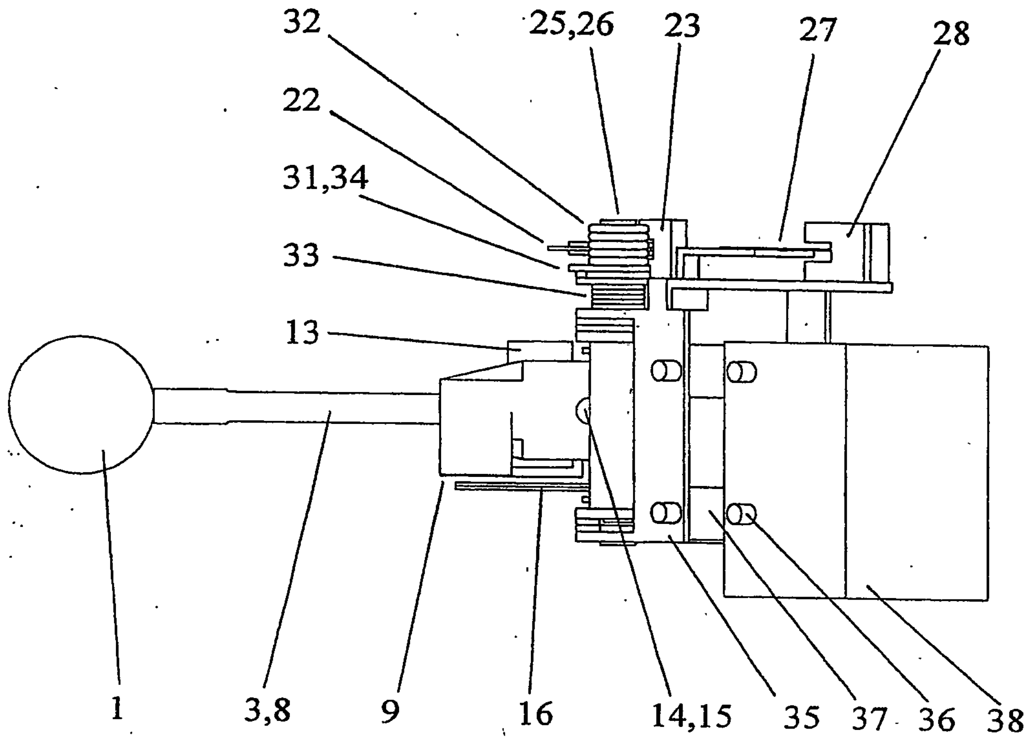

FIGURE 8

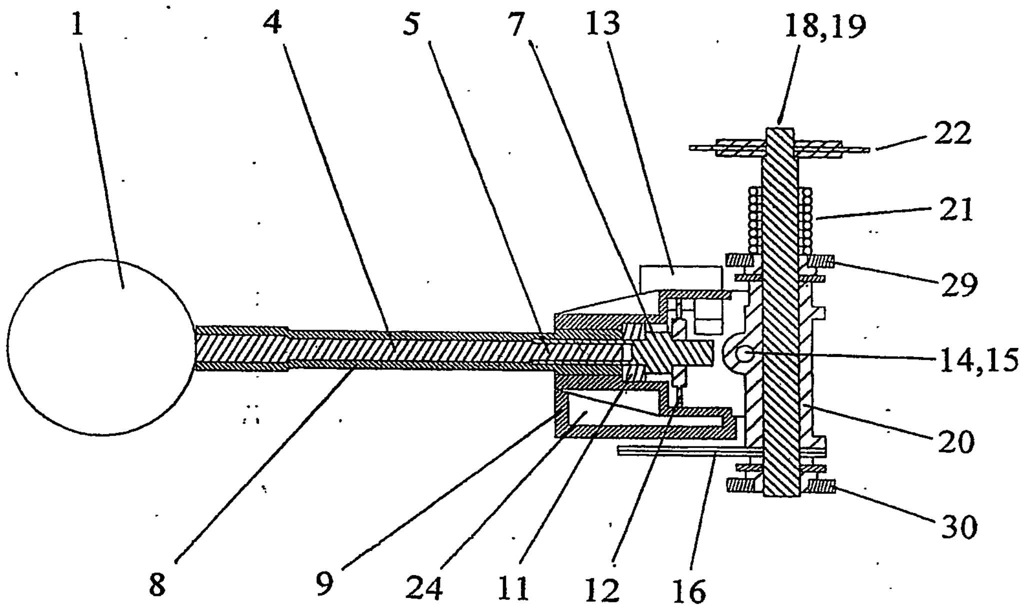

FIGURE 9

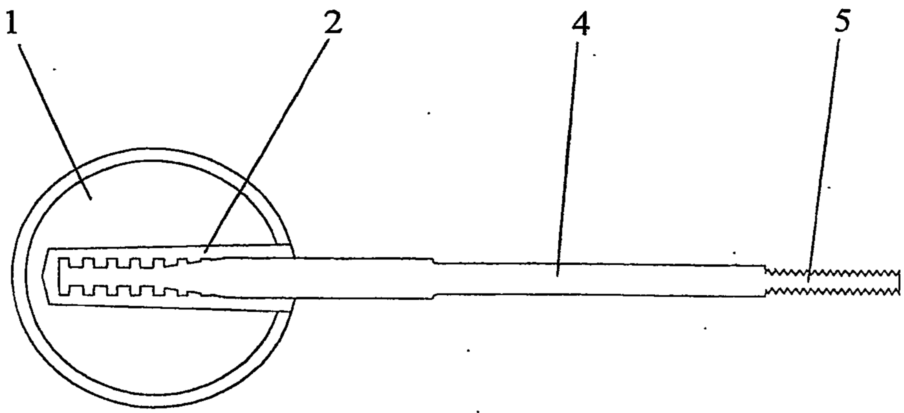

FIGURE 10

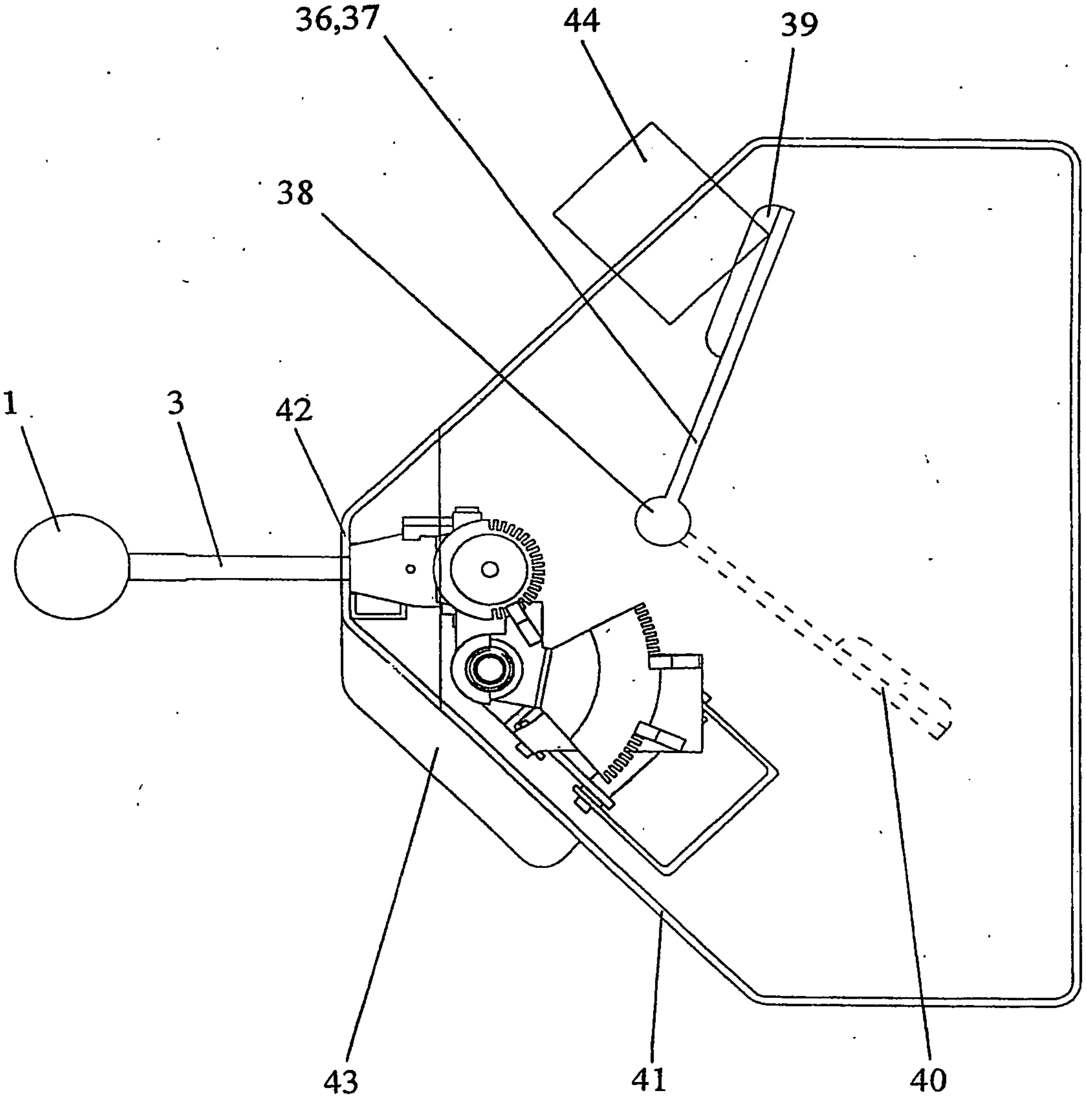

FIGURE 11

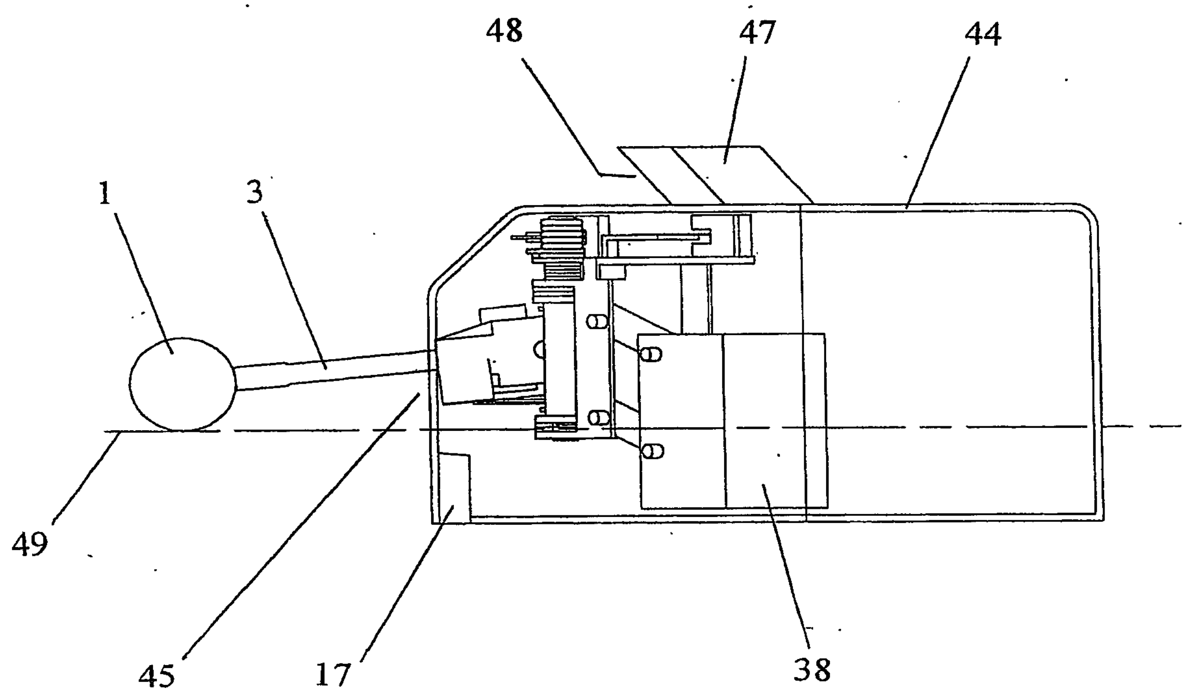

FIGURE 12

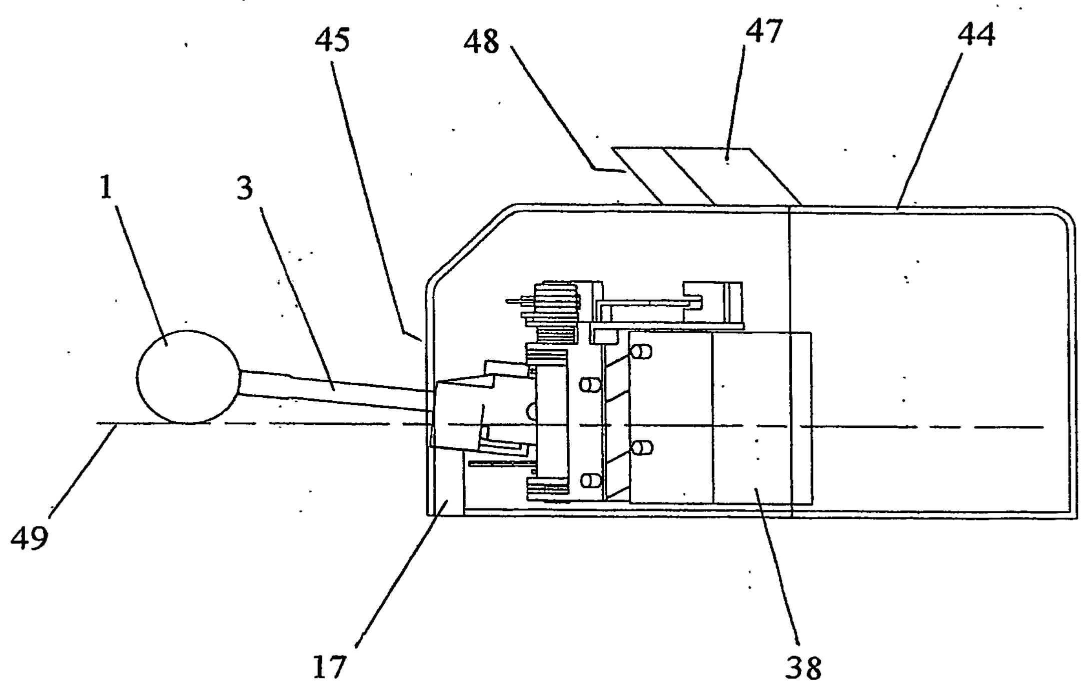

FIGURE 13

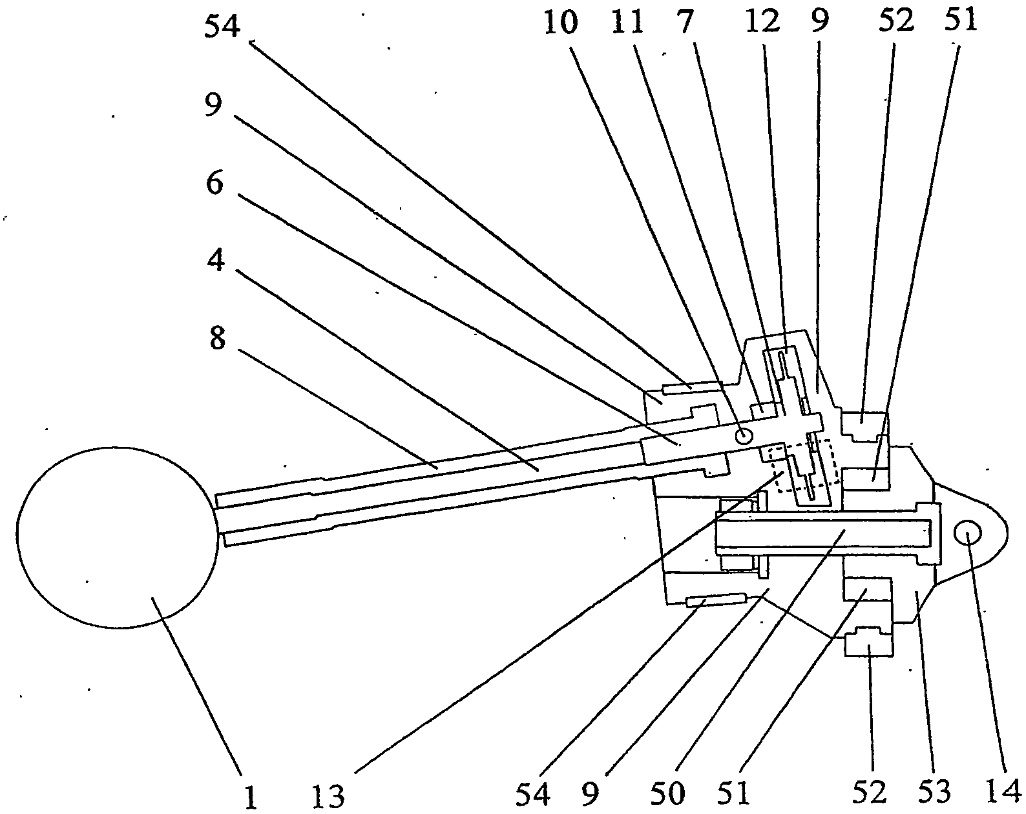

FIGURE 14